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PART I

Bioventing Pilot Test Work Plan for Area D Bulk Fuel Storage and Building 102 Base Fuel Station Ellsworth AFB, South Dakota

PART II

Interim Pilot Test Results Report for Area D Bulk Fuel Storage and Building 102 Base Fuel Station Ellsworth AFB, South Dakota

Prepared For

Air Force Center for Environmental Excellence
Brooks AFB, Texas

and

28 CES/CEV
Ellsworth AFB, South Dakota

ES
Engineering-Science, Inc.
1700 BROADWAY, SUITE 900
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November 1993

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PART I

BIOVENTING PILOT TEST WORK PLAN FOR
AREA D BULK FUEL STORAGE
AND
BUILDING 102 BASE FUEL STATION

ELLSWORTH AFB, SOUTH DAKOTA

November 1993

Prepared for:

Air Force Center for Environmental Excellence
Brooks AFB, Texas

and

28 CES/CEV
Ellsworth AFB, South Dakota

Prepared by:

Engineering-Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

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FIGURES

PART I

BIOVENTING PILOT TEST WORK PLAN FOR AREA D BULK FUEL STORAGE AND BUILDING 102 BASE FUEL STATION ELLSWORTH AFB, SOUTH DAKOTA

1.0 INTRODUCTION

This work plan presents the scope of multiphase bioventing pilot tests for *in situ* treatment of fuel-contaminated soils at Area "D" Bulk Fuel Storage (Area D), Building 102 Base Fuel Station (Building 102), and one optional site at Ellsworth Air Force Base (AFB), South Dakota. The locations of the test sites with respect to the base are shown on Figure 1.1. The pilot tests will be performed by Engineering-Science, Inc. (ES). The three primary objectives of the proposed pilot tests are: 1) to assess the potential for supplying oxygen throughout the contaminated soil interval, 2) to determine the rate at which indigenous microorganisms will degrade fuel when supplied with oxygen-rich soil gas, and 3) to evaluate the potential for sustaining these rates of biodegradation until fuel contamination is remediated to concentrations below regulatory standards.

Each pilot test will be conducted in two phases. The initial phase will consist of construction on vent wells (VWs) and vapor monitoring points (MPs), *in situ* respiration tests, and an air permeability test. This initial test is expected to take approximately 3 weeks. During the second phase, the bioventing systems will be operated and monitored over a 1-year period.

If bioventing proves to be an effective means of remediating soil contamination at these sites, pilot test data may be used to design full-scale remediation systems and to estimate the time required for site cleanup. An added benefit of the pilot testing at these sites is that a significant amount of the fuel contamination should be biodegraded during the 1-year pilot test, as the testing will take place within highly contaminated soils at the sites.

Additional background information on the development and recent success of the bioventing technology is found in the document entitled *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing* (Hinchee et al., 1992). This protocol document will serve as the primary reference for pilot test well designs and the detailed procedures to be used during the test.

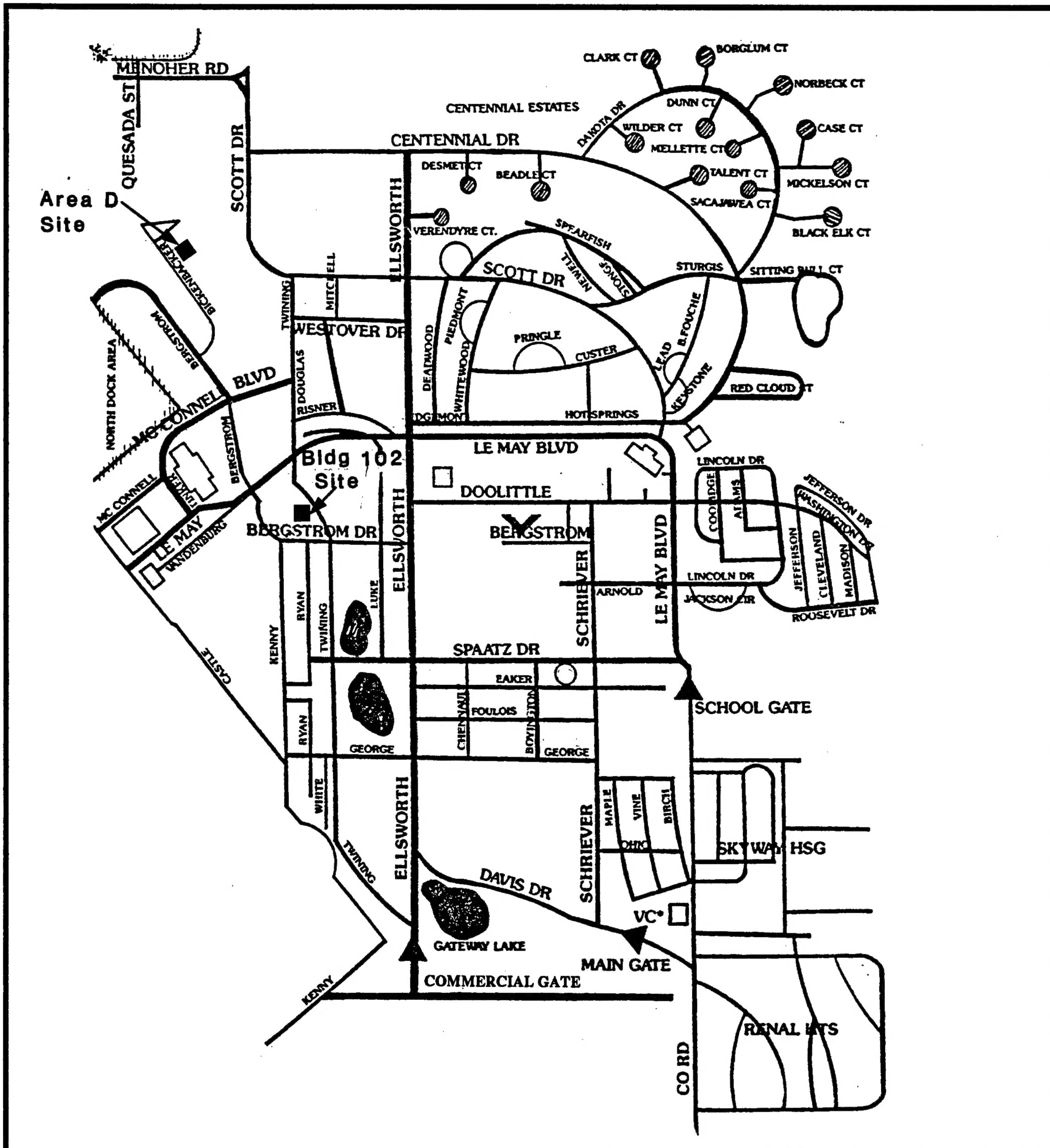

FIGURE 1.1

SITE LOCATIONS WITH RESPECT TO BASE

ELLSWORTH AFB, SOUTH DAKOTA

ENGINEERING–SCIENCE, INC.
Denver, Colorado

ES

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2.0 AREA D, BULK FUEL STORAGE

2.1 Site Description

2.1.1 Site History and Location

Area D, Bulk Fuel Storage Facility, is located in the west-central part of Ellsworth AFB and is currently used for the storage and transfer of JP-4 jet fuel, diesel fuel, and gasoline. The location of Area D with respect to the base is shown in Figure 1.1. The site proposed for the bioventing pilot study is located near Building 8215, Transfer and Unloading Pumphouse, in the southwestern part of Area D (Figure 2.1).

The Area D facility consists of two aboveground storage tanks (ASTs) containing JP-4 jet fuel, four underground storage tanks (USTs), 2 JP-4 dispensers, and a railroad spur with fuel unloading headers. The ASTs, located to the northwest of building 8215, have a combined capacity of 90,000 barrels (bbl). Fuel can be unloaded by three different systems. Bulk fuels can be unloaded either from rail tank cars, from conventional tanker trucks, and via an underground pipeline coming from Area C (located near the commercial entrance to the base). The fuels can be unloaded into conventional tanker trucks and hauled to the final destination.

Four USTs at Area D are described by FMG, Inc. (1992a). A "slush" tank for holding JP-4 fuel that has been inadvertently released from the system is located at the east end of the UST area. A a 1,500 gallon "hold over" tank, near the northeast side of Building 8215, is used to hold a mixture of fuels and water when no other storage capacity is available. A 25,000-gallon gasoline UST and a 25,000-gallon diesel fuel UST are located near the center of the UST area (Figure 2.1).

2.1.2 Site Geology

Because the bioventing technology is applied to unsaturated soils, this section will primarily discuss soils above the shallow aquifer. Soils at Area D consist of lean clay with gravel and sand to approximately 13 feet below ground surface (bgs), and well-graded gravel from approximately 13 to 17 feet bgs. The top of the groundwater surface occurred at a depth of approximately 16 feet bgs in February 1992 (FMG, Inc., 1992a), but may vary seasonally.

2.1.3 Site Contaminants

The primary soil contaminants at this site are fuel-related petroleum hydrocarbons which have been detected in the soils at depths ranging from 4 to 16 feet bgs. Total petroleum hydrocarbons (TPH) were detected at 3,010 parts per million (ppm) in soil boring BH7 at a depth of 4 to 6 feet bgs (Figure 2.1). In MW2 at a depth of 15 to 17 feet bgs, TPH were detected at 1,200 ppm. The volatile organic compounds (VOCs) benzene, toluene, ethylbenzene, and xylenes (BTEX) were detected in samples collected from the soil borings and borings for monitoring wells at concentrations ranging from 1.3 to 98.4 ppm (FMG, Inc., 1992a).

2.2 Pilot Test Activities

The purpose of this section is to describe the pilot test activities to take place at Area D. The proposed locations and construction details for the central VWs and

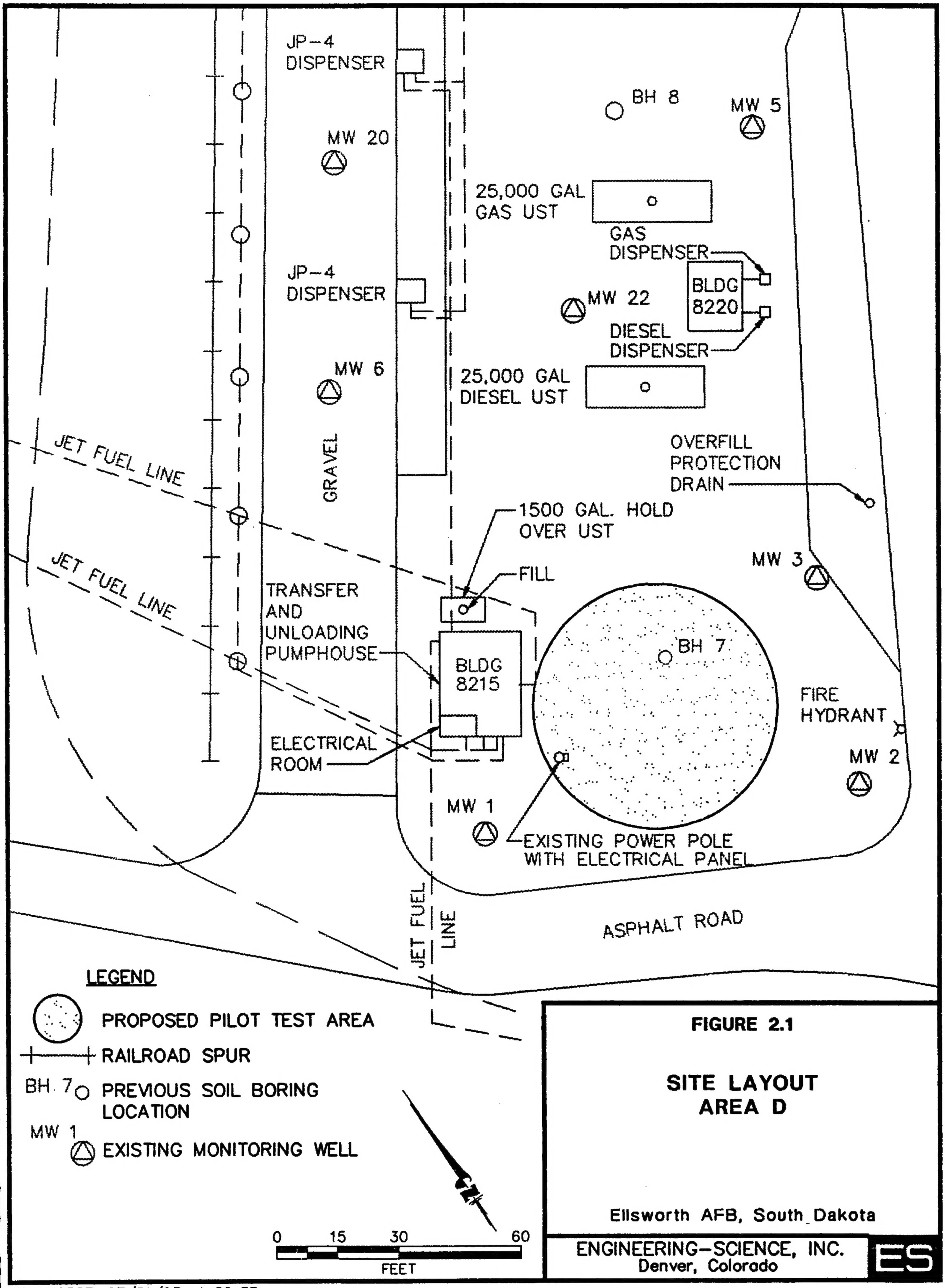

FIGURE 2.1

SITE LAYOUT AREA D

Ellsworth AFB, South Dakota

ENGINEERING-SCIENCE, INC.
Denver, Colorado

ES

93DN0567, 07/21/93 at 09:35

vapor MPs are discussed. The blower configuration that will be used to inject air (oxygen) into contaminated soils is also discussed in this section. Finally, a brief description of the pilot test procedures is provided.

The bioventing technology is intended to remediate contamination only in the unsaturated zone. Therefore, pilot test activities will be confined mainly to unsaturated soils. The central VW will be completed to approximately 2 or 3 feet below the current groundwater table to provide oxygen to the deepest levels of the unsaturated zone, in case the groundwater table recedes due to pressurization or natural fluctuation. No dewatering will take place during the pilot tests.

Existing monitoring wells will not be used as primary air injection or vapor MPs. However, monitoring wells which have a portion of their screened interval above the water table may be used as vapor MPs or to measure the composition of background soil gas.

2.2.1 Layout of Pilot Test Components

A general description of criteria for siting a central VW and vapor MPs is included in the protocol document (Hinchee et al., 1992). Figure 2.2 illustrates the proposed locations of the central VW and MPs at this site. The final locations of these wells may vary slightly from the proposed locations if significant fuel contamination is not observed in the boring for the central VW. Based on previous site investigation data and a site visit, the VW should be located approximately 35 feet southeast of Building 8215, near the existing soil borehole BH7 location. Soils in this area are expected to be TPH contaminated and oxygen depleted (< 2%), and biological activity should be stimulated by oxygen-rich soil gas ventilation during pilot test operations.

Due to the relatively shallow depth of contamination at this site, the potential for low permeability soils, and the experience ES has had with similar soil types, the potential radius of venting influence around the central VW is expected to be 25 to 30 feet. Three vapor MPs (MPA, MPB, and MPC) will be located within a 30-foot radius of the central VW (Figure 2.2).

2.2.2 Vent Wells

The VW will be constructed of 4-inch-diameter Schedule 40 polyvinyl chloride (PVC), with a 15-foot interval of 0.04-inch slotted screen set at 5 to 20 feet bgs. Flush-threaded PVC casing and screen with no organic solvents or glues will be used. The filter pack will be clean, well-rounded silica sand with a 6-9 grain size and will be placed in the annular space to 1 foot above the screened interval. A 4-foot-thick bentonite seal will be placed directly over the filter pack to produce an air-tight seal above the screened interval. The bentonite seal, consisting of granular bentonite, will be placed in 6-inch layers, with each layer hydrated in place with potable water prior to the addition of subsequent layers. The remaining annular space will then be filled to the ground surface with a bentonite/cement grout. A complete seal is critical to prevent injected air from short-circuiting to the surface during the bioventing test. Figure 2.3 illustrates the proposed central VW construction detail for this site.

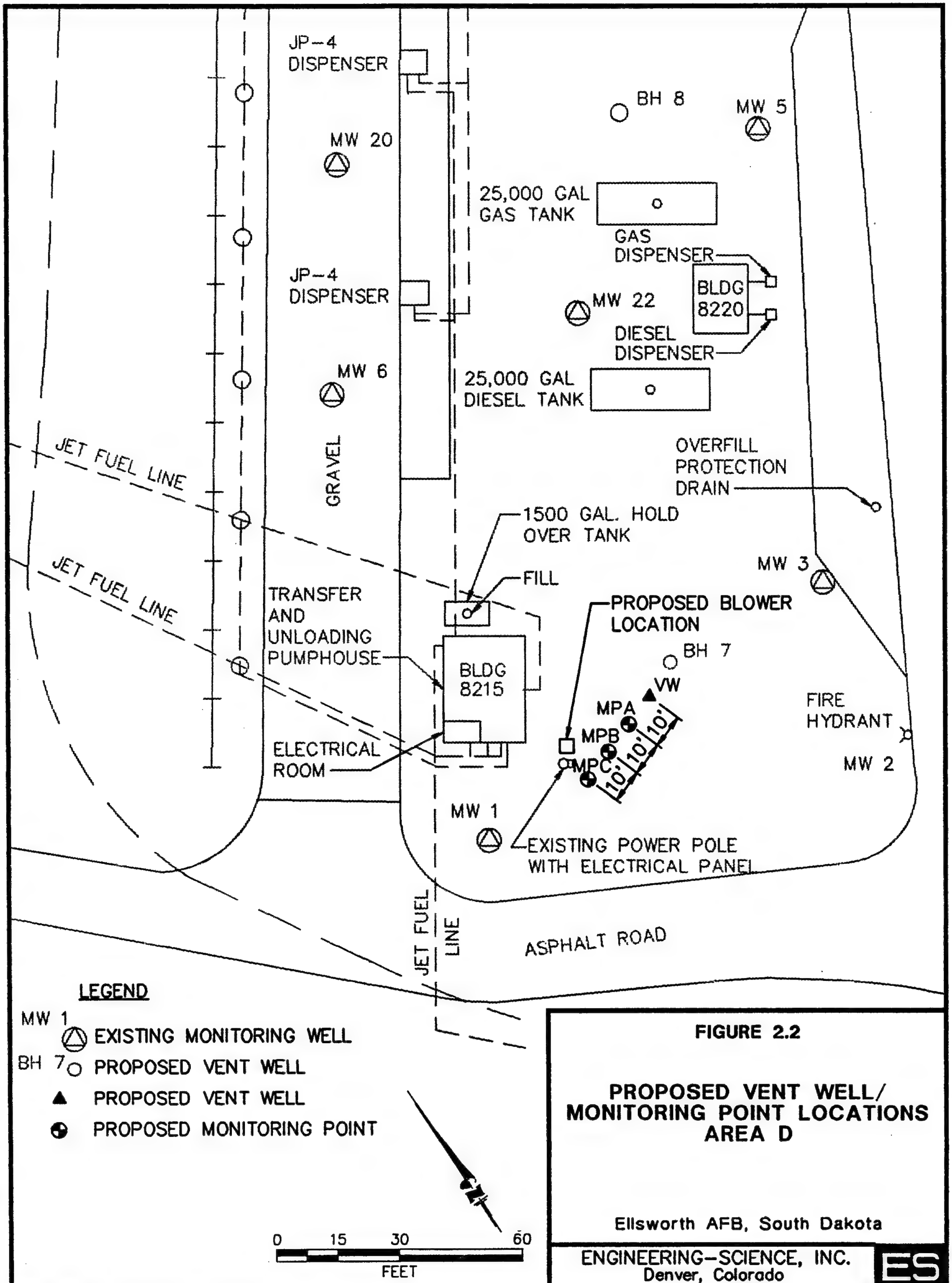

FIGURE 2.2

PROPOSED VENT WELL/ MONITORING POINT LOCATIONS AREA D

Ellsworth AFB, South Dakota

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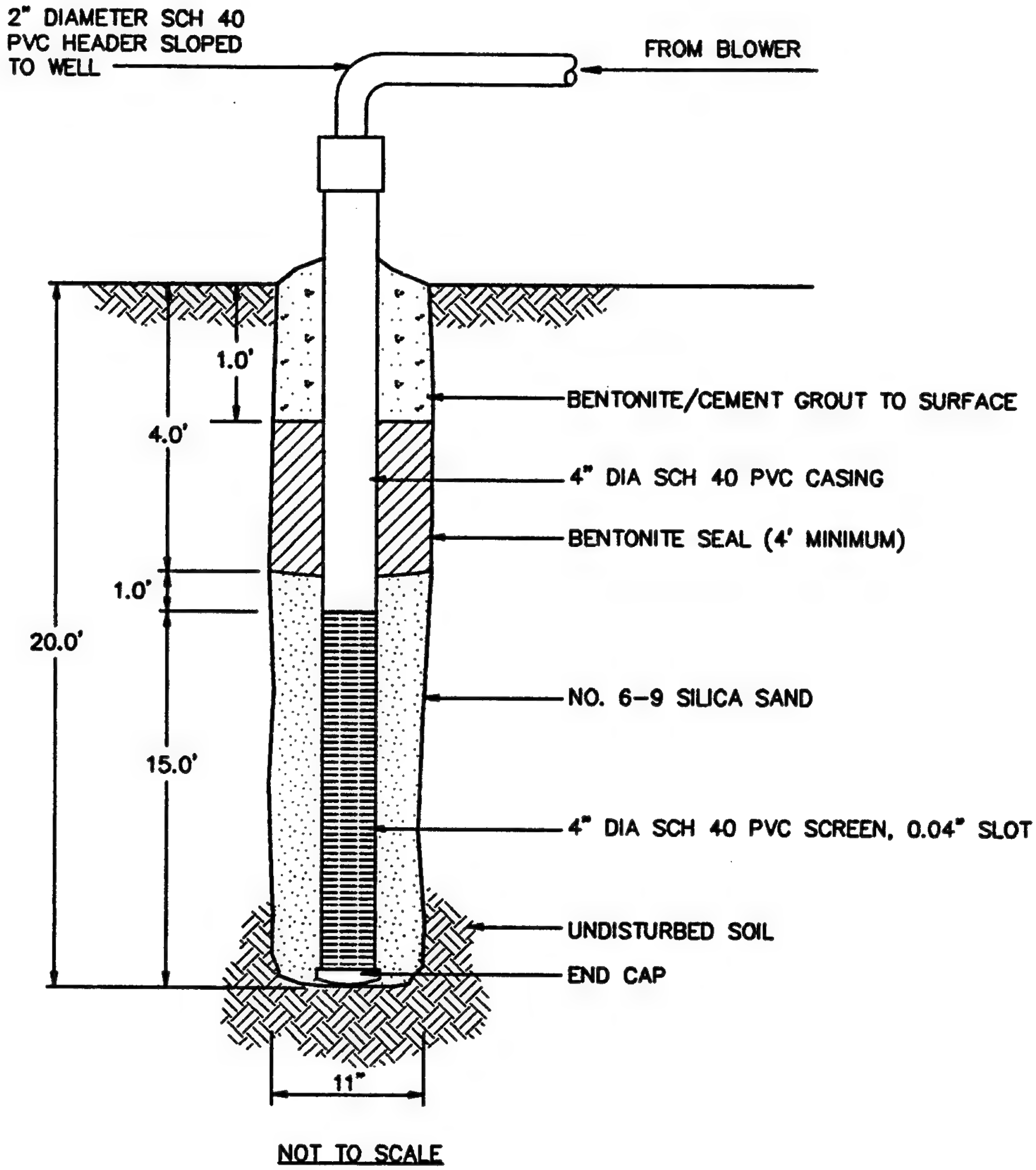

FIGURE 2.3

PROPOSED INJECTION VENT WELL CONSTRUCTION DETAIL AREA D

Ellsworth AFB, South Dakota

ENGINEERING–SCIENCE, INC.
Denver, Colorado

93DN0560, 07/21/93 at 09:40

2.2.3 Monitoring Points

A typical multi-depth vapor MP installation for this site is shown in Figure 2.4. Soil gas oxygen and carbon dioxide concentrations will be monitored at depths of 5 feet, 10 feet, and 15 feet at each location. Soil temperature will be monitored using thermocouples instaled at depths of 5 feet and 15 feet at MPA. Multi-depth monitoring will confirm that the entire soil profile is receiving oxygen and will be used to measure fuel biodegradation rates at the three depths.

Each MP will be constructed with three vapor probes, placed within sand intervals, separated by bentonite seals. Vapor probes, constructed of 6-inch-long sections of 1-inch-diameter PVC well screen, will be placed within a 2-foot layer of 6-9 silica sand. The annular spaces between the three screened MP intervals will be sealed with bentonite to isolate the monitoring intervals. The bentonite seals will consist of granular bentonite hydrated in place. The bentonite within 2 feet above and below the sand intervals will be placed in approximately 6-inch layers and hydrated with potable water prior to placement of subsequent layers to assure complete saturation and hydration of the bentonite. Additional details on VW and MP construction are presented in Section 4 of the protocol document (Hinchee et al., 1992).

2.2.4 Blower System

A 3-horsepower positive-displacement blower capable of injecting air over a wide range of flow rates and pressures will be used to conduct the initial air permeability test. Figure 2.5 is a schematic of a typical air injection system used for pilot testing. The maximum power requirement anticipated for this pilot test is 230-volt, single-phase, 30-amp service. Additional details on power supply requirements are described in Section 5.0, Base Support Requirements.

2.2.5 Air Permeability Test

The objective of the air permeability test is to determine the extent of the subsurface that can be oxygenated using one VW. Prior to initiating the test, baseline concentrations of oxygen, carbon dioxide, and total volatile hydrocarbons (TVH) will be measured in soil gas from the VW and each MP screened interval.

Air will be injected into the VW using the blower unit, and pressure response will be measured at each MP with differential pressure gauges to determine the region influenced by the unit. Oxygen will also be monitored in the MPs to ascertain whether oxygen levels in the soil increase as the result of air injection. One air permeability test lasting 4 to 24 hours will be performed at this site.

2.2.6 *In Situ* Respiration Test

The objective of the *in situ* respiration test is to determine the rate at which soil bacteria degrade petroleum hydrocarbons. Respiration tests will be performed at every vapor MP where bacterial biodegradation of hydrocarbons is indicated by low initial oxygen levels and elevated carbon dioxide concentrations in the soil gas. Using 1-standard-cubic-feet-per-minute (scfm) pumps, air will be injected into approximately four MP depth intervals containing low levels (<2%) of oxygen. A

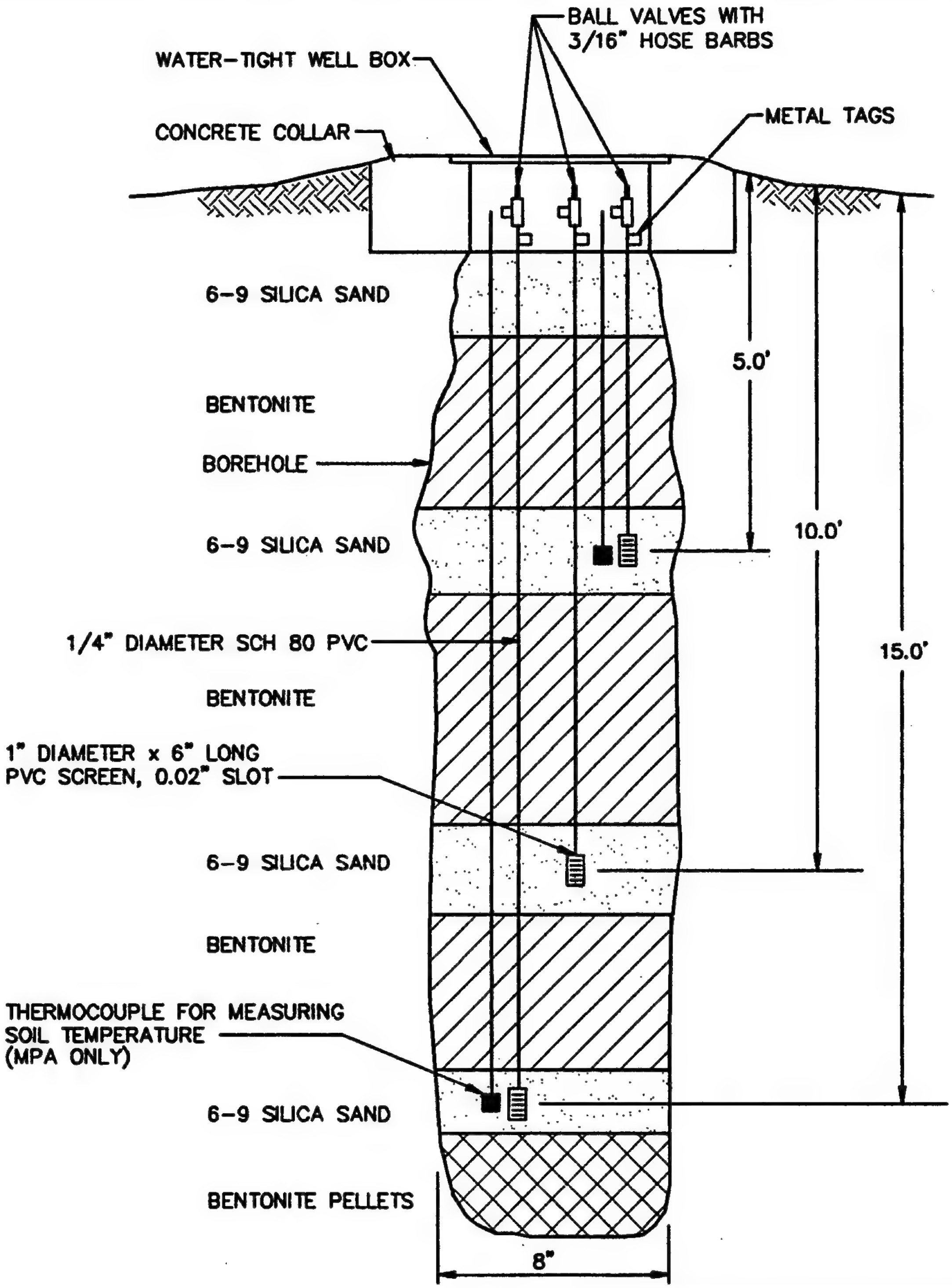

FIGURE 2.4

PROPOSED MONITORING POINT CONSTRUCTION DETAIL AREA D

Ellsworth AFB, South Dakota

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ENGINEERING-SCIENCE, INC.
Denver, Colorado

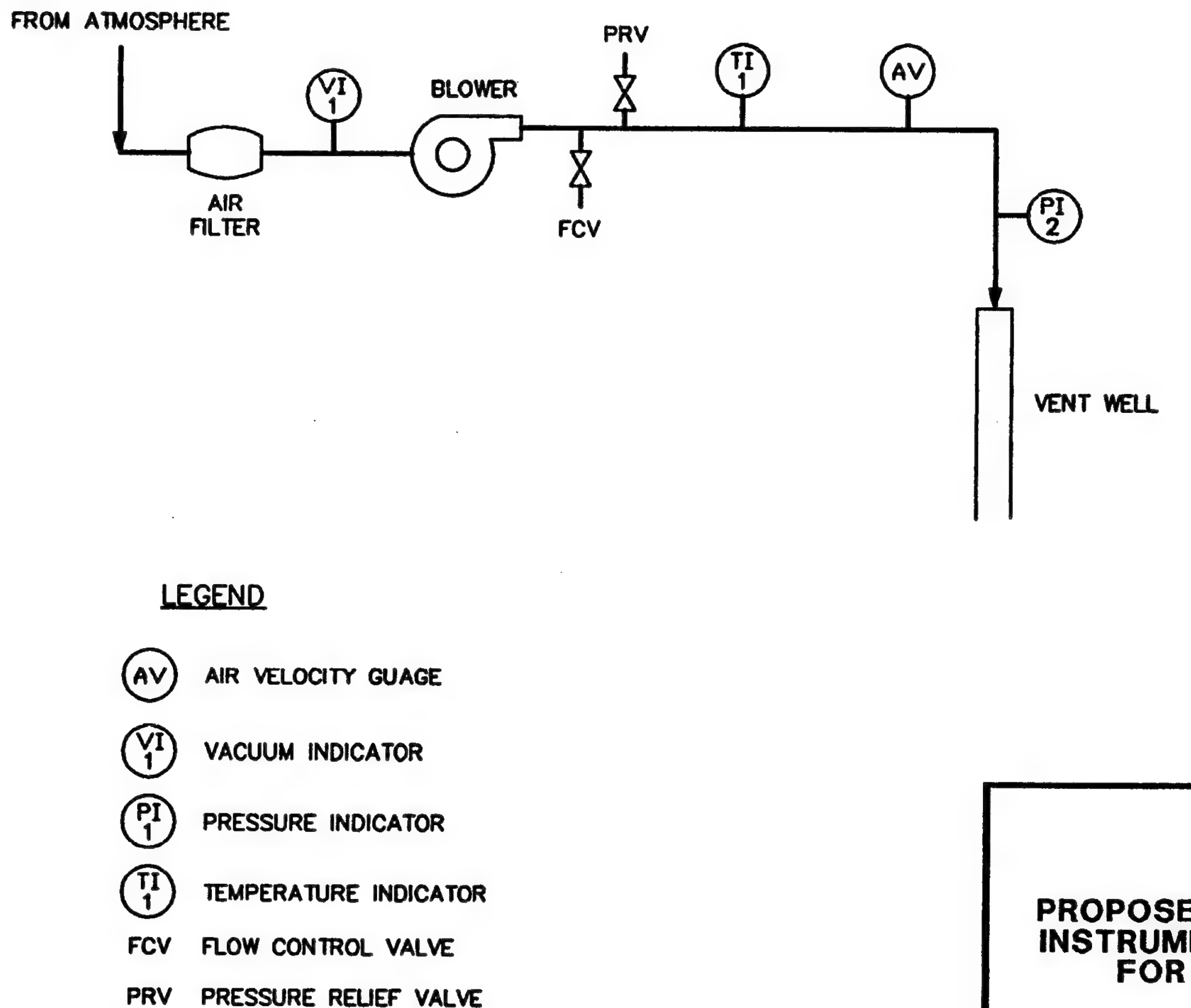

FIGURE 2.5

PROPOSED BLOWER SYSTEM INSTRUMENTATION DIAGRAM FOR AIR INJECTION

Ellsworth AFB, South Dakota

ENGINEERING-SCIENCE, INC.
Denver, Colorado

93DN0565, 07/21/93 at 09:51

20-hour air injection period will be used to oxygenate local contaminated soils. At the end of the 20-hour air injection period, the air supply will be cut off, and oxygen, carbon dioxide, and TVH concentrations will be monitored for the following 48 to 72 hours. The decline in oxygen and increase in carbon dioxide concentrations over time will be used to estimate rates of bacterial degradation of fuel residuals. Helium will also be injected into the selected MP intervals to determine the effectiveness of the bentonite seals. Additional details on the *in situ* respiration test procedures are provided in Section 5.7 of the protocol document (Hinchee et al., 1992).

2.2.7 Extended Pilot Test Bioventing System

An extended, 1-year bioventing system will also be installed at Area D. The system will be chosen based upon the results of the initial respiration and air permeability tests. However, it is anticipated that the extended test blower will have flow rates in the range of 10 to 20 scfm and will not exceed 2.5 horsepower. A base electrician will be requested to wire the blower to line power. The blower will be housed in a small, prefabricated shed to provide protection from the weather.

The system will be in operation for 1 year, and every 6 months ES personnel will conduct an *in situ* respiration test to monitor the long-term performance of this bioventing system. Weekly system checks will be performed by Ellsworth AFB personnel. If required, major maintenance of the blower unit will be performed by ES personnel. Detailed blower system information and a maintenance schedule will be included in the operation and maintenance (O&M) manual to be provided to the base. More detailed information regarding the test procedures can be found in the protocol document.

3.0 BUILDING 102, BASE FUEL STATION

3.1 Site Description

3.1.1 History and Location

Building 102 is located in the northwest part of the base, near the north end of Bickenbacker Court (Figure 1.1). The site, also referred to as the Base Fuel Station, is currently being used as a fueling station for base vehicles. The area proposed for the bioventing pilot study is located north of the canopy and the USTs (Figure 3.1).

The fueling station was constructed in 1965 with the installation of a 12,000-gallon gasoline UST and a 2,000-gallon diesel fuel UST. In 1979, a 5,000-gallon diesel fuel UST was installed approximately 10 feet northeast of the 2,000-gallon diesel UST. No leaks were detected in any of the three tanks during leak testing performed in October 1990. A release was first noticed during leak-detection monitoring well installation in July and August 1991, around the canopy area. The 12,000-gallon gasoline UST was subsequently emptied. Gasoline is presently stored in one of the smaller USTs that formerly contained diesel fuel (FMG Inc., 1992b).

3.1.2 Site Geology

The soil profile at this site generally consists of lean sandy clay to a depth of 9 feet, and well-graded gravel with interbedded layers of clayey sand to a depth of 25

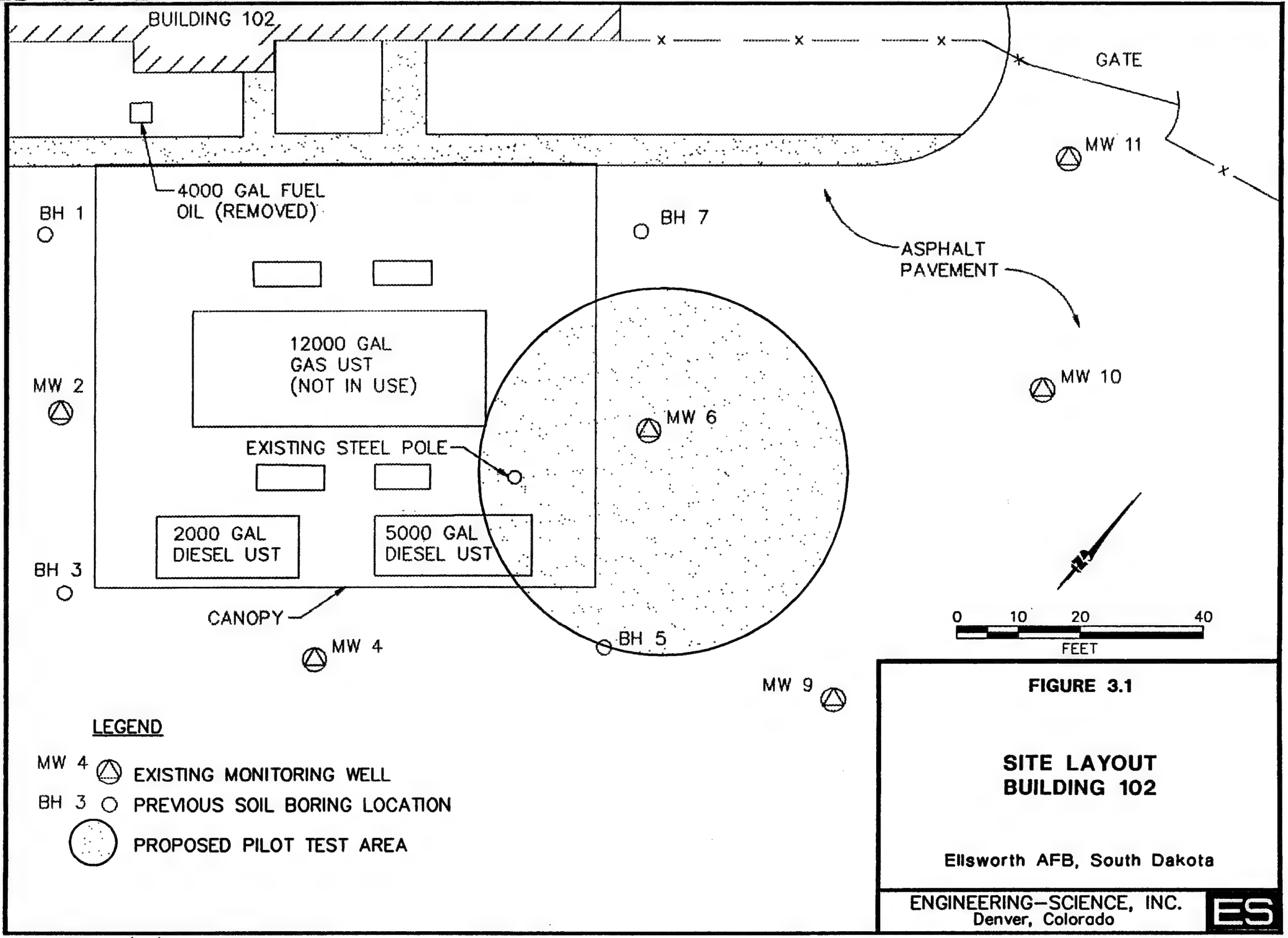

FIGURE 3.1

SITE LAYOUT
BUILDING 102

Ellsworth AFB, South Dakota

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feet. Groundwater was encountered at approximately 17 feet bgs; however, groundwater fluctuations of 1 foot can occur (FMG, Inc., 1992b).

3.1.3 Site Contaminants

The primary contaminants at this site are gasoline-related petroleum hydrocarbons which have migrated to depths of approximately 15 to 17 feet bgs, where shallow groundwater is encountered. Free product was observed in three monitoring wells, located downgradient from the suspected source. Laboratory analyses of soils for TPH (as gasoline) indicated that soils are most highly contaminated to the east of the canopy area. Most soil contamination appears to be confined to a relatively thin zone extending a few feet above the water table surface. TPH concentrations in soil were highest (9,390 ppm) in MW6 at a depth of 15 to 17 feet bgs. BTEX were also detected at high concentrations (1,315 ppm) in MW6 soils (FMG, Inc., 1992b).

3.2 Pilot Test Activities

The purpose of this section is to describe the pilot test activities to take place at the Building 102 site. The proposed locations and construction details for the central VW and vapor MPs are discussed. The blower configuration that will be used to extract soil gas from, and inject air (oxygen) into contaminated soils is also discussed in this section. Finally, a brief description of the pilot test procedures is provided.

The bioventing technology is intended to remediate contamination only in the unsaturated zone. Therefore, pilot test activities will be confined mainly to unsaturated soils. The central VW will be completed to approximately 2 or 3 feet below the current groundwater table to provide oxygen to the deepest levels of the unsaturated zone, in case the groundwater table recedes due to natural fluctuation. No dewatering will take place during the pilot tests. Existing monitoring wells will not be used as primary air extraction/injection or vapor MPs. However, monitoring wells which have a portion of their screened interval above the water table may be used as vapor MPs or to measure the composition of background soil gas.

3.2.1 Layout of Pilot Test Components

A general description of criteria for siting a central VW and vapor MPs are included in the protocol document (Hinchee et al., 1992). Figure 3.2 illustrates the proposed locations of the central VW and MPs at this site. Based on previous site investigation data and a site visit, the VW should be located approximately 10 feet northeast of the canopy, near existing groundwater monitoring well MW6. The final locations of these wells may vary slightly from the proposed locations if significant fuel contamination is not observed in the boring for the central VW. Soils in this area are expected to be TPH contaminated and oxygen depleted (< 2%), and biological activity should be stimulated by oxygen-rich soil gas ventilation during pilot test operations.

Due to the relatively shallow depth of contamination at this site, the potential for low permeability soils, and the experience ES has had with similar soil types, the potential radius of venting influence around the central VW is expected to be 25 to

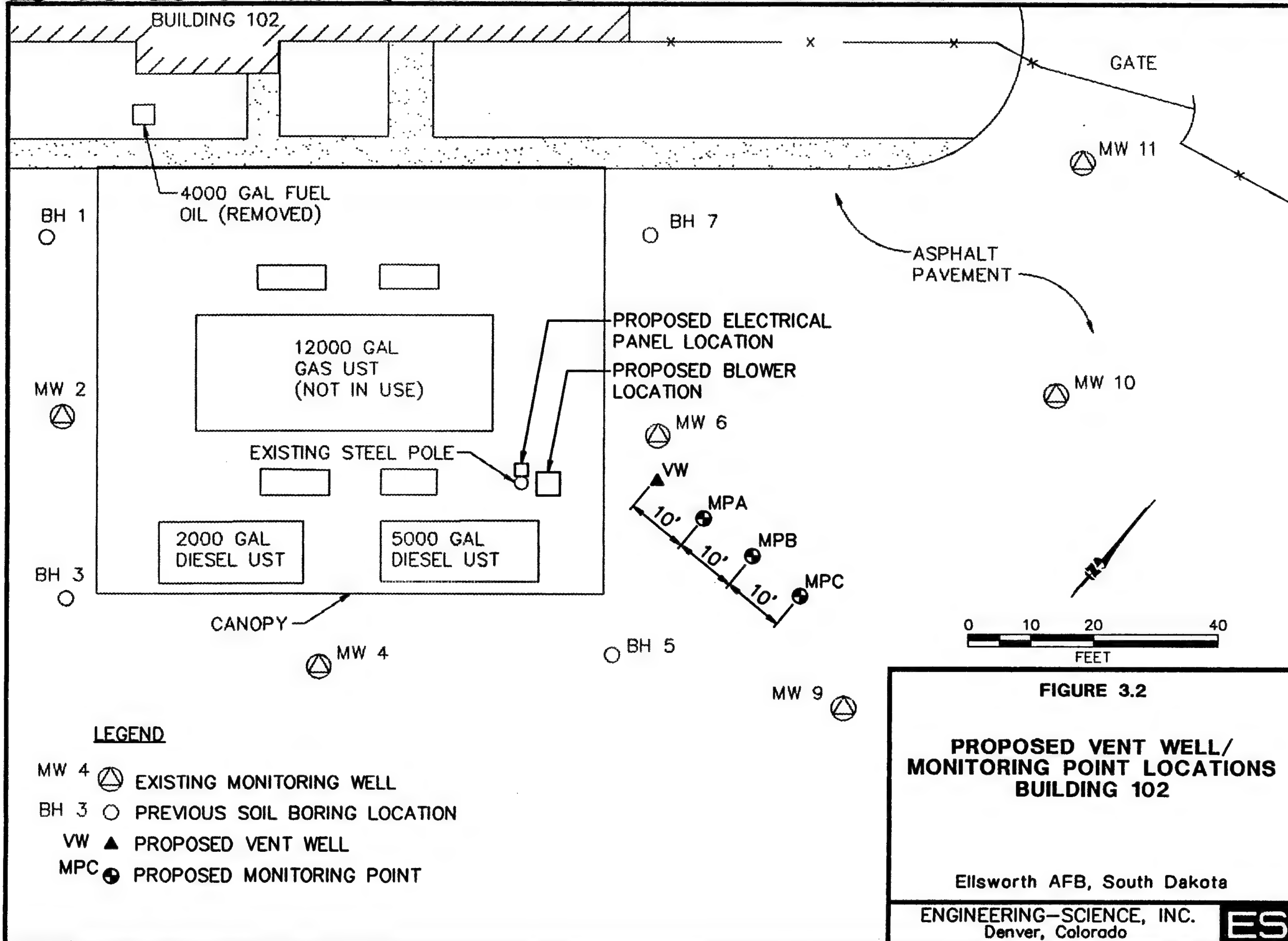

FIGURE 3.2

PROPOSED VENT WELL/ MONITORING POINT LOCATIONS BUILDING 102

Ellsworth AFB, South Dakota

ENGINEERING–SCIENCE, INC.
Denver, Colorado

ES

93DN0566, 07/21/93 at 09:58

30 feet. Three vapor MPs (MPA, MPB, and MPC) will be located within a 30-foot radius of the central VW (Figure 3.2).

3.2.2 Vent Wells

The VW will be constructed of 4-inch diameter Schedule 40 polyvinyl chloride (PVC), with a 15-foot interval of 0.04-inch slotted screen set at 5 to 20 feet bgs. Flush-threaded PVC casing and screen with no organic solvents or glues will be used. The filter pack will be clean, well-rounded silica sand with a 6-9 grain size and will be placed in the annular space to one foot above the screened interval. A 4-foot thick bentonite seal will be placed directly over the filter pack to produce an air-tight seal above the screened interval. The bentonite seal, consisting of granular bentonite, will be placed in 6-inch layers, with each layer hydrated in place with potable water prior to the addition of subsequent layers. The remaining annular space will then be filled to the ground surface with a bentonite/cement grout. A complete seal is critical to prevent injected air from short-circuiting to the surface during the bioventing test. Figure 3.3 illustrates the proposed central VW construction detail for this site.

3.2.3 Monitoring Points

A typical multi-depth vapor MP installation for this site is shown in Figure 3.4. Soil gas oxygen and carbon dioxide concentrations will be monitored at depths of 5 feet, 12 feet, and 16 feet at each location. Soil temperature will be monitored using thermocouples instaled at depths of 5 feet and 16 feet at MPA. Multi-depth monitoring will confirm that the entire soil profile is receiving oxygen and be used to measure fuel biodegradation rates at the three depths.

Each MP will be constructed with three vapor probes, placed within sand intervals, separated by bentonite seals. Vapor probes, constructed of 6-inch-long sections of 1-inch-diameter PVC well screen, will be placed within a 2-foot layer of 6-9 silica sand. The annular spaces between the three screened MP intervals will be sealed with bentonite to isolate the monitoring intervals. The bentonite seals will consist of granular bentonite hydrated in place. The bentonite within 2 feet above and below the sand intervals will be placed in approximately 6-inch layers and hydrated with potable water prior to placement of subsequent layers to assure complete saturation and hydration of the bentonite. Additional details on VW and MP construction are presented in Section 4 of the protocol document (Hinchee et al., 1992).

3.2.4 Blower System

A 3-horsepower positive-displacement blower capable of extracting soil vapors over a wide range of flow rates and pressures will be used to conduct the initial air permeability test. Figure 3.5 is a schematic of a typical air injection/extraction system used for pilot testing. The maximum power requirement anticipated for this pilot test is 230-volt, single-phase, 30-amp service. Additional details on power supply requirements are described in Section 5.0, Base Support Requirements.

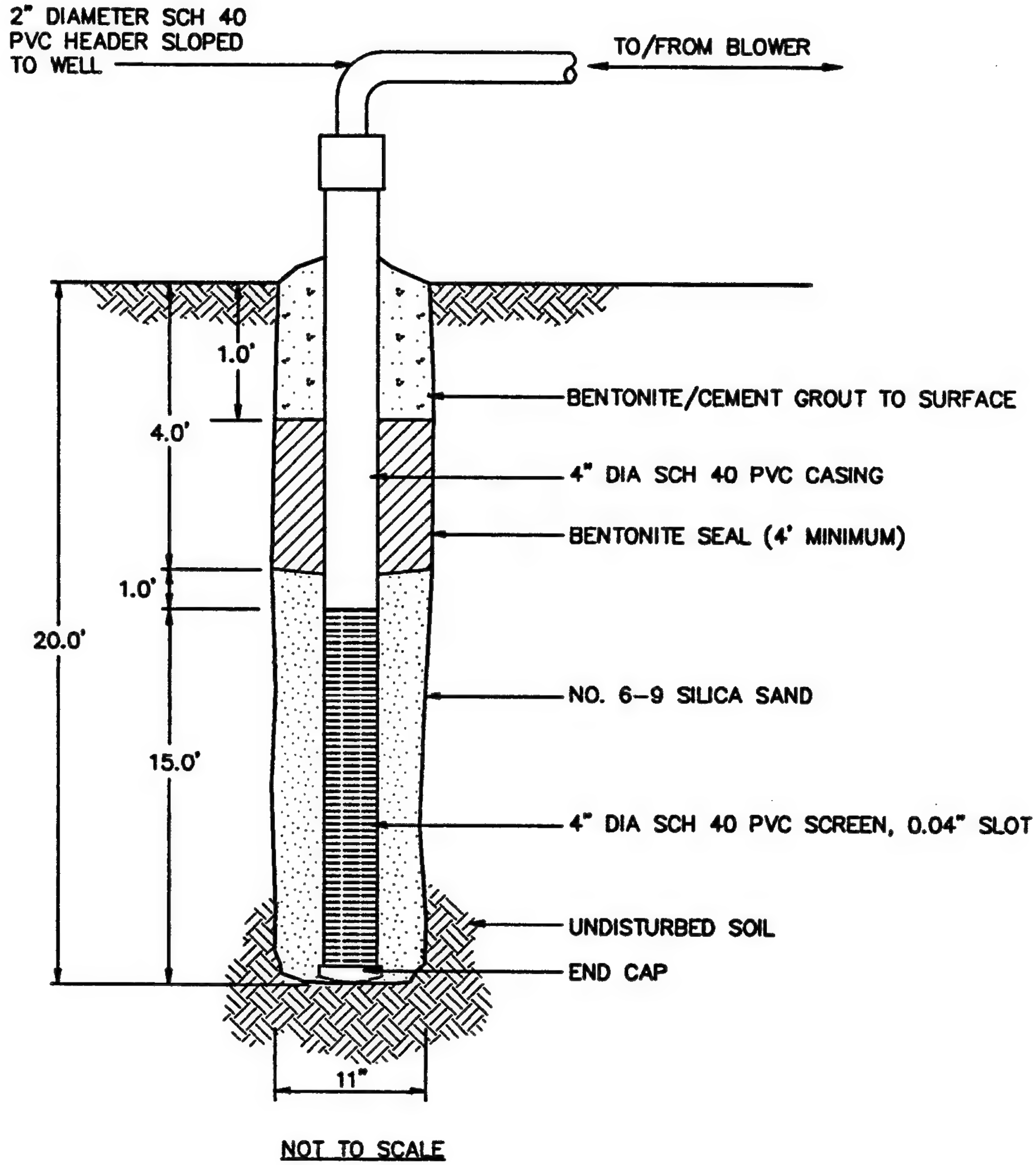

FIGURE 3.3

PROPOSED INJECTION/EXTRACTION VENT WELL CONSTRUCTION DETAIL BUILDING 102

Ellsworth AFB, South Dakota

ENGINEERING-SCIENCE, INC.
Denver, Colorado

93DN0562, 07/21/93 at 10:16

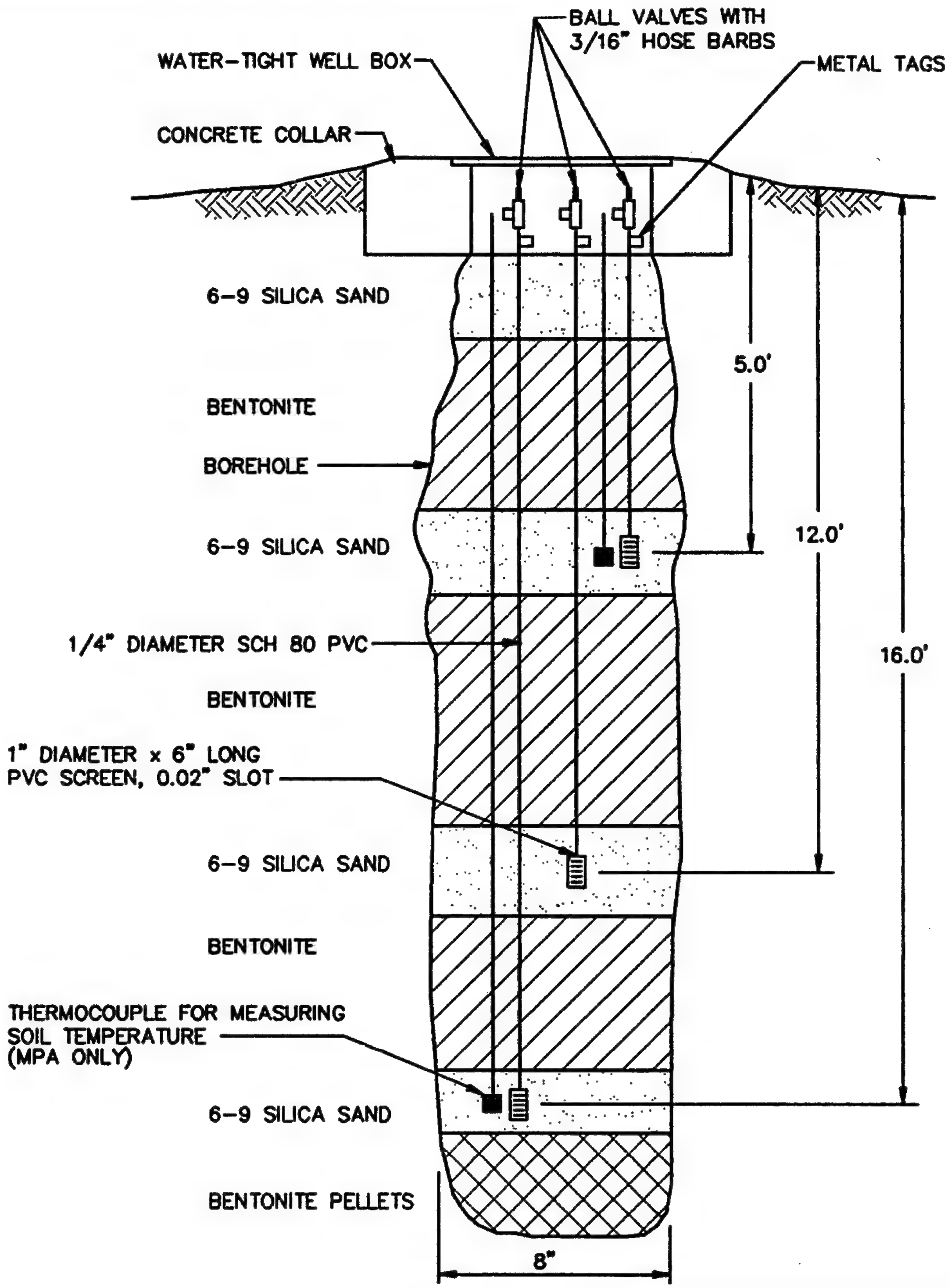

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FIGURE 3.4

PROPOSED MONITORING POINT CONSTRUCTION DETAIL BUILDING 102

Ellsworth AFB, South Dakota

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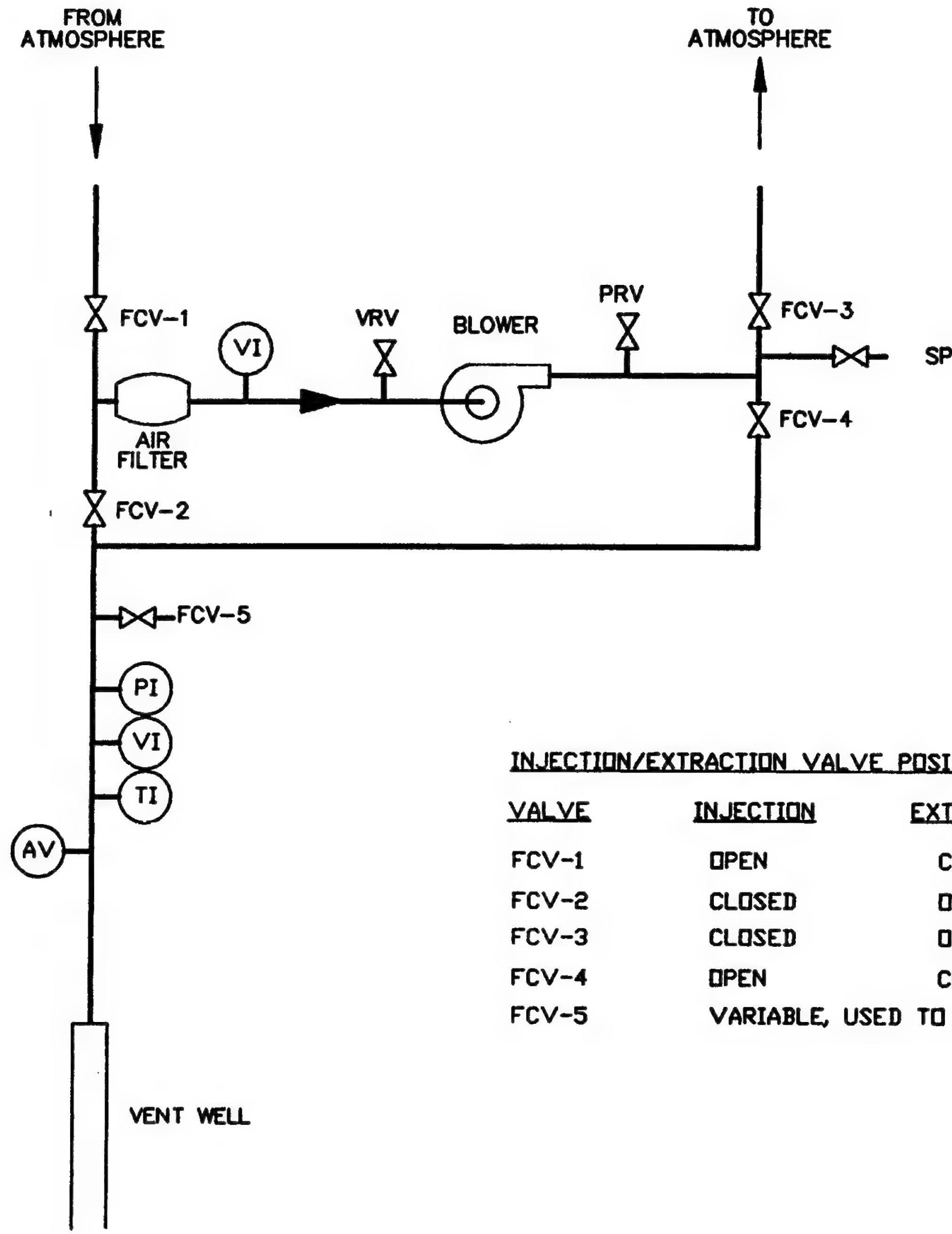

LEGEND

AV	AIR VELOCITY GUAGE
VI	VACUUM INDICATOR
PI	PRESSURE INDICATOR
TI	TEMPERATURE INDICATOR
PRV	PRESSURE RELIEF VALVE
VRV	VACUUM RELIEF VALVE
SP	SAMPLE PORT
FCV	FLOW CONTROL VALVE

INJECTION/EXTRACTION VALVE POSITION

VALVE	INJECTION	EXTRACTION
FCV-1	OPEN	CLOSED
FCV-2	CLOSED	OPEN
FCV-3	CLOSED	OPEN
FCV-4	OPEN	CLOSED
FCV-5	VARIABLE, USED TO CONTROL FLOW RATES	

FIGURE 3.5

PROPOSED INJECTION/ EXTRACTION BLOWER SYSTEM INSTRUMENTATION DIAGRAM BUILDING 102

ELLSWORTH AFB, SOUTH DAKOTA

ENGINEERING-SCIENCE, INC.
Denver, Colorado

93DN0637, 07/22/93 at 08:40

3.2.5 Air Permeability Test

The objective of the air permeability test is to determine the extent of the subsurface that can be oxygenated using one VW. In contrast to testing at Area D, where air will be injected into the VW, soil vapors will be extracted from the VW to avoid the possibility of displacing explosive vapors into the adjacent fuel station. The soil vapors in the vicinity of the VW are expected to contain low concentrations of oxygen (the result of microbial respiration) and high concentrations of TVH. As these vapors are withdrawn from the VW, soil gas from the adjacent, clean soils (containing higher concentrations of oxygen), will be drawn toward the VW.

Air will be extracted from the VW using the blower unit, and pressure (vacuum) response will be measured at each MP with differential pressure gauges to determine the region influenced by the unit. Oxygen will also be monitored in the MPs to ascertain whether oxygen levels in the soil increase as the result of air extraction. One air permeability test lasting approximately 12 to 48 hours will be performed at this site.

The extracted soil gas will be vented to the atmosphere and monitored for TVH. TVH concentrations, and the rate of decrease of TVH concentration, in the extracted soil gas will be used to determine whether the extended blower system will initially be operated in an injection or extraction mode. These data will also be used to estimate the time required for the system to be operated in the injection mode. See Section 3.2.7, Extended Pilot Test Bioventing System for additional discussion of this topic.

3.2.6 *In Situ* Respiration Test

The objective of the *in situ* respiration test is to determine the rate at which soil bacteria degrade petroleum hydrocarbons. Respiration tests will be performed at every vapor MP where bacterial biodegradation of hydrocarbons is indicated by low initial oxygen levels and elevated carbon dioxide concentrations in the soil gas. Depending on oxygen levels measured at the end of the permeability test, the respiration test will begin immediately following the permeability test (if oxygen levels are uniformly above 15 percent) or air will be injected into selected MP intervals using 1-scfm pumps (if oxygen levels are below 15 percent). If air injection is necessary, air will be injected into approximately four MP depth intervals containing low initial levels (<2%) of oxygen. A 20-hour air injection period will be used to oxygenate local contaminated soils.

At the end of the 20-hour air injection period, or immediately following the permeability test, the air supply will be cut off, and oxygen and carbon dioxide levels will be monitored for the following 48 to 72 hours. The decline in oxygen and increase in carbon dioxide concentrations over time will be used to estimate rates of bacterial degradation of fuel residuals. If air injection is necessary, helium will also be injected into the selected MP intervals to determine the effectiveness of the bentonite seals. Additional details on the *in situ* respiration test procedures are provided in Section 5.7 of the protocol document (Hinchee et al., 1992).

3.2.7 Extended Pilot Test Bioventing System

An extended, 1-year bioventing system will also be installed at the Building 102 site. The system will be chosen based upon the results of the initial respiration and air

permeability tests. However, it is anticipated that the extended test blower will have a flow rate in the range of 10 to 20 scfm, and will not exceed 2.5 horsepower. A base electrician will be requested to wire this explosion-proof blower to line power. The possibility of an explosive atmosphere in the vicinity of the fuel pumps requires that the electrical wiring for the blower also be explosion-proof. The blower will be housed in a small, prefabricated shed to provide protection from the weather.

Based upon soil gas TVH concentrations measured during the permeability and respiration tests, the blower system will initially be operated either in an extraction or injection mode. If high TVH concentrations are measured, indicating a possibility for migration of explosive vapors into Building 102, the extended-test blower system will initially be operated in an extraction configuration, otherwise it will be operated as an injection system (Figure 3.5).

If the system is initially operated as an extraction system, the extracted soil gas will be periodically monitored for TVH concentrations. The extraction system will be operated in a pulsed mode to maximize biodegradation and minimize fuel volatilization and air emissions. After approximately 2 months of soil vapor extraction, and based upon measured TVH concentrations in the extracted soil gas, the blower system will be converted to an air injection system. Air monitoring inside Building 102 will be conducted immediately following conversion of the blower to an injection system to confirm that explosive vapors are not migrating into the adjacent fuel station building. The system will then operate as an injection system for the remainder of the 1-year period.

The system will be in operation for 1 year, and every 6 months ES personnel will conduct an *in situ* respiration test to monitor the long-term performance of this bioventing system. Weekly system checks will be performed by Ellsworth AFB personnel. If required, major maintenance of the blower unit will be performed by ES personnel. Detailed blower system information and a maintenance schedule will be included in the O&M manual to be provided to the base. More detailed information regarding the test procedures can be found in the protocol document.

4.0 OPTIONAL SITE

One optional site may be chosen for an additional pilot test. This site will be selected based upon site history, previous investigation data, and soil gas surveys conducted by ES. If the soil gas survey results show high soil gas TVH concentrations and low (<2 percent) oxygen concentrations, one or more soil borings will drilled to confirm soil contamination. If soil contamination is confirmed, and no other conditions are encountered that would preclude a pilot test, then a third pilot test will be performed at the selected site. Test procedures would be similar to those described in Section 2 or 3, depending upon site conditions.

5.0 BACKGROUND WELL MONITORING POINT

The construction of an additional vapor MP may be required to measure background levels of oxygen and carbon dioxide and to determine if natural carbon sources are contributing to oxygen uptake during the *in situ* respiration tests. This background MP

would be installed in an area of uncontaminated soil and in the same or similar stratigraphic formations as the MPs to be installed. The background well would be similar in construction to the MPs (Figures 2.4 and 3.4), and would be screened at 2 or more depths. ES will require some assistance from Ellsworth AFB in selecting an appropriate location for the proposed background MP.

Existing groundwater monitoring wells located in areas with no fuel contamination may be suitable for use as background wells. These wells must have a portion of their screened interval above the water table, and initial soil gas samples must contain oxygen in excess of 15 percent to be used as background MPs. Additional information regarding background wells may be found in Section 4.3 of the protocol document (Hinchee et al., 1992).

6.0 SOIL AND SOIL GAS SAMPLING

6.1 Soil Samples

Three soil samples will be collected from each pilot test area during the installation of the VW and MPs. Sampling procedures will follow those outlined in the protocol document. One sample will be collected from the most contaminated interval of each VW boring, and one sample will be collected from the interval of highest apparent contamination in each of the borings for the two MPs closest to the VW. Soil samples will be analyzed for total recoverable petroleum hydrocarbons (TRPH), BTEX, soil moisture, pH, particle sizing, alkalinity, total iron, and nutrients.

Soil samples for laboratory analysis will be collected using a split-spoon sampler containing brass tube liners. Soil samples collected in the brass tubes will be immediately trimmed, and the ends will be sealed with Teflon® fabric held in place by plastic caps. Soil samples will be labelled following the nomenclature specified in the protocol document (Section 5), wrapped in plastic, and placed in a cooler maintained at a temperature of 4 degrees centigrade for shipment. A chain-of-custody form will be filled out, and the cooler will be shipped to the PACE, Inc. laboratory in Novato, California for analysis. This laboratory has been audited by the Air Force and meets all quality assurance/quality control and certification requirements for the State of California.

6.2 Soil Gas Samples

A total hydrocarbon vapor analyzer will be used during augering to screen split-spoon soil samples for intervals of high fuel contamination. Initial and final soil gas samples will be collected in 1-liter SUMMA® cannisters in accordance with the Bioventing Field Sampling Plan (Engineering-Science, Inc., 1992) from the VW and from the MPs closest to and furthest from the VW. Additionally, these soil gas samples will be used to predict potential air emissions, to determine the reduction in BTEX and total volatile hydrocarbons (TVH) during the 1-year test, and to detect any migration of these vapors from the source area.

Soil gas sample canisters will be placed in a small cooler and packed with foam pellets to prevent excessive movement during shipment. Samples will not be sent on ice to prevent condensation of hydrocarbons. A chain-of-custody form will be filled

out, and the cooler will be shipped to the Air Toxics, Inc. laboratory in Rancho Cordova, California for analysis.

7.0 HANDLING OF DRILL CUTTINGS

Drill cuttings from all VW and MP borings will be collected in U.S. Department of Transportation (DOT) approved containers. The containers will be labeled and placed in the Ellsworth AFB hazardous materials storage area. These drill cuttings will become the responsibility of Ellsworth AFB, and will be analyzed, handled, and disposed of in accordance with the current procedures for ongoing remedial investigations. This project is expected to generate approximately 24 55-gallon drums of cuttings.

8.0 EXCEPTIONS TO PROTOCOL PROCEDURES

The procedures that will be used to measure the air permeability of the soil and *in situ* respiration rates are described in Sections 4 and 5 of the protocol document (Hinchee et al., 1992). No exceptions to the protocol procedures are anticipated.

9.0 BASE SUPPORT REQUIREMENTS

The following base support is needed prior to the arrival of the drilling subcontractor and the ES pilot test team:

- Assistance in obtaining drilling and digging permits.
- Assistance in finding a suitable location for the background MP. The background well location should be in an area with no fuel contamination and with similar stratigraphy to that of the bioventing pilot test sites. Preferably, 110-volt receptacle power will be available within 200 feet of the background MP location.
- Installation of a new power distribution panel or breaker box at Building 102 near the proposed blower location (Figure 3.2). This location may require explosion-proof wiring and receptacles. Modification of the existing panel mounted on the power pole near the proposed blower location at the Area D site (Figure 2.2). Each panel should include 208-volt, 30-amp, single-phase service with one 208-volt receptacle and two 115-volt receptacles.
- Provision of any paperwork required to obtain gate passes and security badges for approximately two ES employees and two drillers. Vehicle passes will be needed for one ES truck and trailer, and for the drill rig and service truck.

During the initial testing, the following base support is needed:

- Parking space for one 8- x 20-foot laboratory and equipment trailer located as close to each pilot test area as practical.
- A decontamination pad or other designated area where the driller can clean augers between borings.
- Acceptance of responsibility by Ellsworth AFB for drill cuttings from VW and MP borings, including additional sampling, to determine disposal options. ES will provide the results of TRPH and BTEX soil analysis to help characterize drill cuttings.
- Twelve square feet of desk space and a telephone in a building located as close to the sites as practicable.
- The use of a facsimile machine for transmitting 15 to 20 pages of test results.

During the 1-year extended pilot test, base personnel will be required to perform the following activities:

- Check the blower system once per week to ensure that it is operating and to record the air-injection pressure and temperature. Change air filters and blower lubricants when required. ES will provide a brief training session on these procedures and an O&M manual.
- If the blower stops working, notify Mr. John Hall or Mr. Doug Downey, ES-Denver, at (303) 831-8100, or Mr. Sam Taffinder, Air Force Center for Environmental Excellence (AFCEE), at (512) 536-4331.
- Arrange site access for an ES technician to conduct *in situ* respiration tests approximately 6 months and 1 year after the initial pilot tests, and for any blower system repairs or modifications.

10.0 PROJECT SCHEDULE

The following schedule is contingent upon timely approval of this pilot test work plan.

Event	Date
Draft Test Work Plan to AFCEE/Ellsworth AFB	23 July 1993
Begin Initial Pilot Tests	23 August 1993
Complete Initial Pilot Tests	3 September 1993
Interim Results Report	4 November 1993
6-Month Respiration Tests	March 1994
Final Respiration Tests	September 1994

11.0 POINTS OF CONTACT

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Ellsworth AFB, SD 57706-4711
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COM (605) 385-2680

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Mr. Doug Downey
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1700 Broadway, Suite 900
Denver, CO. 80290
(303) 831-8100
Fax (303) 831-8208

12.0 REFERENCES

Engineering-Science, Inc. 1992. *Field Sampling Plan for AFCEE Bioventing*. January.

FMG, Inc., 1992a. *Final Fuel Spill Contamination Survey Report for Project No. 91-7087-4,* Area "D" Bulk Fuel Storage. February.

FMG, Inc., 1992b. *Final Survey Report for Project No. 91-7087-1, Fuel Spill Contamination Survey, Building 102 Base Fuel Station.* November.

Hinchee, R.E., S.K. Ong, R.N. Miller, D.C. Downey, and R. Frandt. January 1992. *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing.*

PART II

DRAFT INTERIM PILOT TEST RESULTS REPORT FOR

AREA D BULK FUEL STORAGE
AND
BUILDING 102 BASE FUEL STATION

ELLSWORTH AFB, SOUTH DAKOTA

November 1993

Prepared for:

Air Force Center for Environmental Excellence
Brooks AFB, Texas

and

28 CES/CEV
Ellsworth AFB, South Dakota

Prepared by:

Engineering-Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

A7-25-14

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PART II

DRAFT
INTERIM PILOT TEST RESULTS REPORT
FOR AREA D BULK FUEL STORAGE AND BUILDING 102 BASE FUEL STATION
ELLSWORTH AFB, SOUTH DAKOTA

Initial bioventing pilot tests were completed by Engineering-Science, Inc. (ES) at Area D Bulk Fuel Storage (Area D) and Building 102 Base Fuel Station (Building 102) at Ellsworth Air Force Base (AFB), South Dakota during the period of August 23 through September 3, 1993. The purpose of this Part II report is to describe the results of the initial pilot tests at Area D and Building 102 and to make specific recommendations for extended testing to determine the long-term impact of bioventing on site contaminants. Descriptions of the history, geology, and contamination at Area D and Building 102 are contained in Part I, the Bioventing Pilot Test Work Plan.

1.0 PILOT TEST DESIGN AND CONSTRUCTION

Installation of an air injection vent well (VW) and three vapor monitoring points (MPs) at each site took place on August 23 through 27, 1993. Drilling services were provided by Layne Western, Inc. of Ames, Iowa, and well installation and soil sampling was directed by Mr. John Hall, the ES site manager. Electrical services for both sites were provided by Muth Electric, Inc. of Rapid City, South Dakota. The following sections describe the final design and installation of the bioventing systems at each site.

1.1 Area D

Two VWs, three MPs, and a blower unit were installed at Area D. The location of the blower unit was changed slightly from that proposed in the work plan to facilitate the installation of electrical power to the blower. Figures 1.1 and 1.2, respectively, depict the locations of and hydrogeologic cross section for the VWs and MPs completed at the site. Boring logs for the MPs and VWs are included in Appendix A. The background MP for this site was the existing groundwater monitoring well MW-24, which is screened several feet above the groundwater surface.

1.1.1 Air Injection Vent Wells

The air injection VWs were installed following procedures described in the Air Force Center for Environmental Excellence (AFCEE) bioventing protocol document

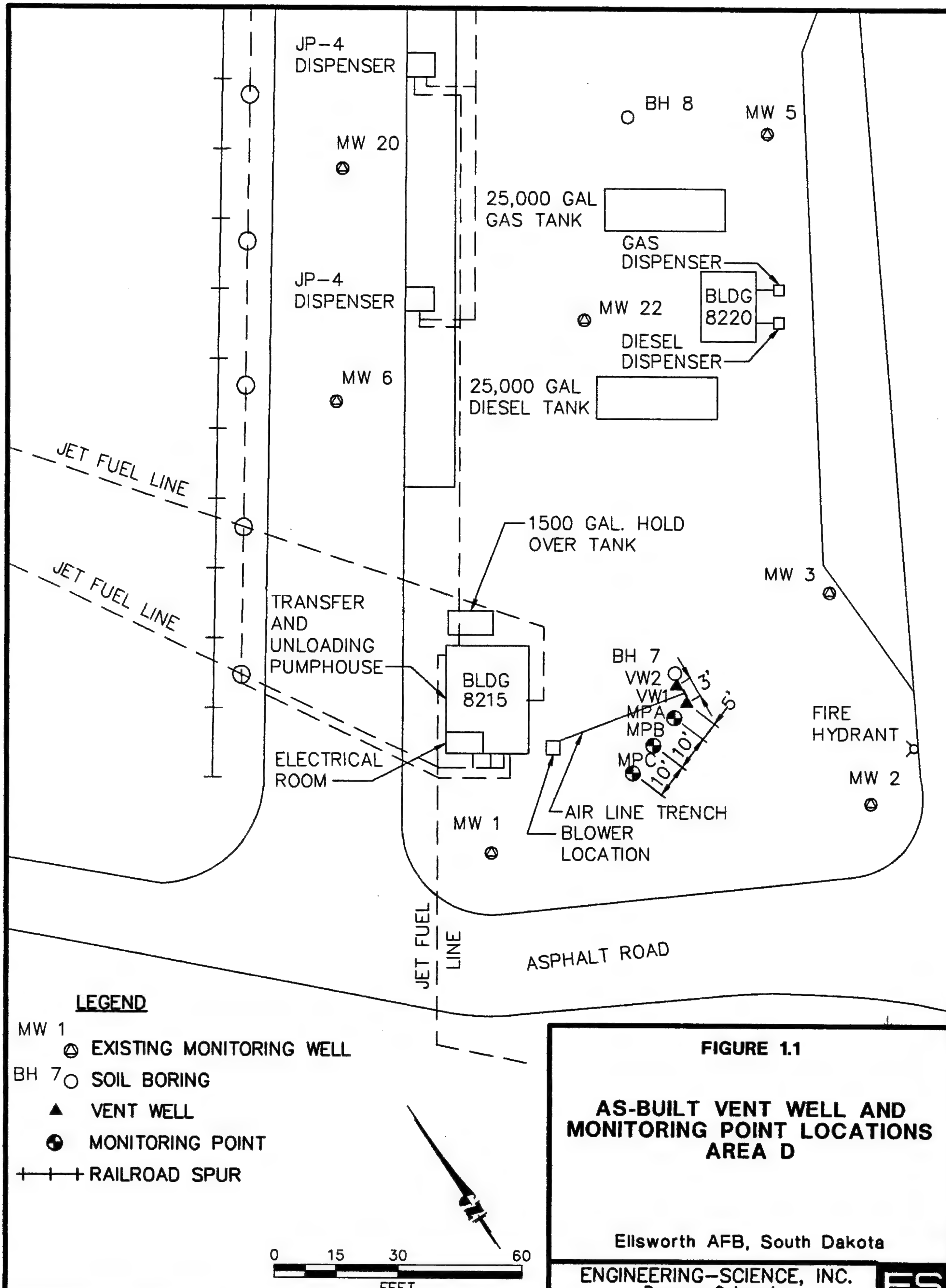


FIGURE 1.1

AS-BUILT VENT WELL AND MONITORING POINT LOCATIONS AREA D

Ellsworth AFB, South Dakota

ENGINEERING-SCIENCE, INC.
Denver, Colorado

ES

93DN1183, 10/28/93 at 15:35

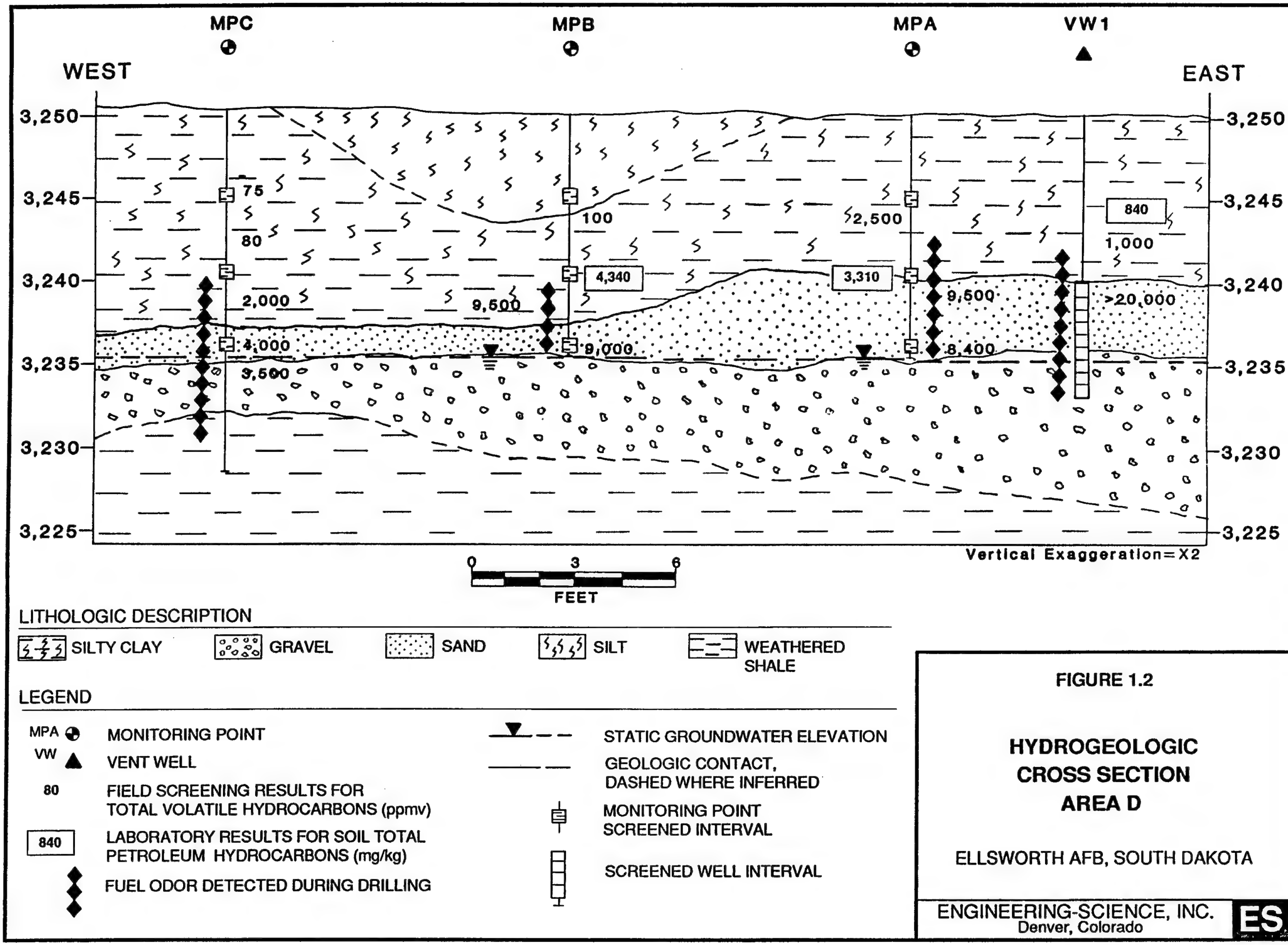


FIGURE 1.2

HYDROGEOLOGIC CROSS SECTION AREA D

ELLSWORTH AFB, SOUTH DAKOTA

(Hinchee et al., 1992). Two VWs were installed at the site to avoid preferential air flow in the subsurface. Silty clay was found at Area D to depths of approximately 10 feet below ground surface (bgs). Sands and gravels were found below this clay. To avoid having the majority of the injected air flow through the more permeable sand and gravel, two wells were installed with screens located at different depths. One well was placed so that it was screened entirely within the clay layer. The other well, placed approximately 3 feet away, was screened entirely within the more permeable layer below. A valve was used to balance flow so that an equal amount of air was flowing into each interval during pilot testing.

A single blower provides air to both VWs. Figures 1.3A and 1.3B show construction details for the VWs. The VWs were installed in contaminated soils with the screened intervals extending from 5 to 10 feet bgs and 10 to 17 feet bgs, respectively. The groundwater surface at this site was approximately 15 feet bgs during the pilot test. The VWs were constructed using 4-inch-diameter, schedule 40 polyvinyl chloride (PVC) casing, with intervals of 0.04-inch slotted PVC screen. The annular space between the well casing and borehole was filled with 6-9 silica sand from the bottom of the borehole to approximately 1 foot above the well screen. Granular bentonite was placed above the sand, hydrated in place, and overlaid with a concrete seal. The tops of both wells were completed with 4-inch-diameter PVC tees with screw caps. Final completions were made with the installation of two 12-inch-diameter flush-mounted well protectors set in concrete.

1.1.2 Monitoring Points

The MP screens were installed at 5-, 10-, and 14-foot depths. The three multidepth MPs (MPA, MPB, and MPC) at this site were constructed as shown in Figure 1.4. Each was constructed using 6-inch sections of 1-inch-diameter PVC well screen with 0.25-inch PVC riser pipes extending to the ground surface. At the top of each riser, a ball valve and a 3/16-inch hose barb was installed. The top of each MP was completed with a flush-mounted metal well protector set in concrete. Thermocouples were installed at the 5- and 14-foot depths at MPA to measure soil temperature variations.

The existing groundwater monitoring well MW-24 was utilized as a background MP. This well is located in an uncontaminated area approximately 440 feet northwest of the Area D pilot test area, and is screened at approximately 10.0 to 35.0 feet bgs.

1.1.3 Blower Unit

A 3-horsepower Roots® positive-displacement blower unit was used at Area D for the initial pilot test, and a 1-horsepower Gast® regenerative blower unit was installed at the site for the extended pilot test. The initial pilot test blower was energized by 208-volt, single-phase, 20-amp line power from a pole-mounted panel installed by Muth Electric, Inc. Power was brought to the panel from an existing panel in Building 8215. The extended pilot test unit is hard-wired to a breaker in the newly installed pole-mounted panel. The 1-horsepower extended pilot test blower was configured to inject approximately 56 standard cubic feet per minute (scfm) for the extended pilot test. The configuration, instrumentation, and specifications for the initial pilot test and extended pilot test units are shown on Figure 1.5. Prior to departing from the site, ES engineers provided an operations and maintenance (O&M) briefing checklist and blower

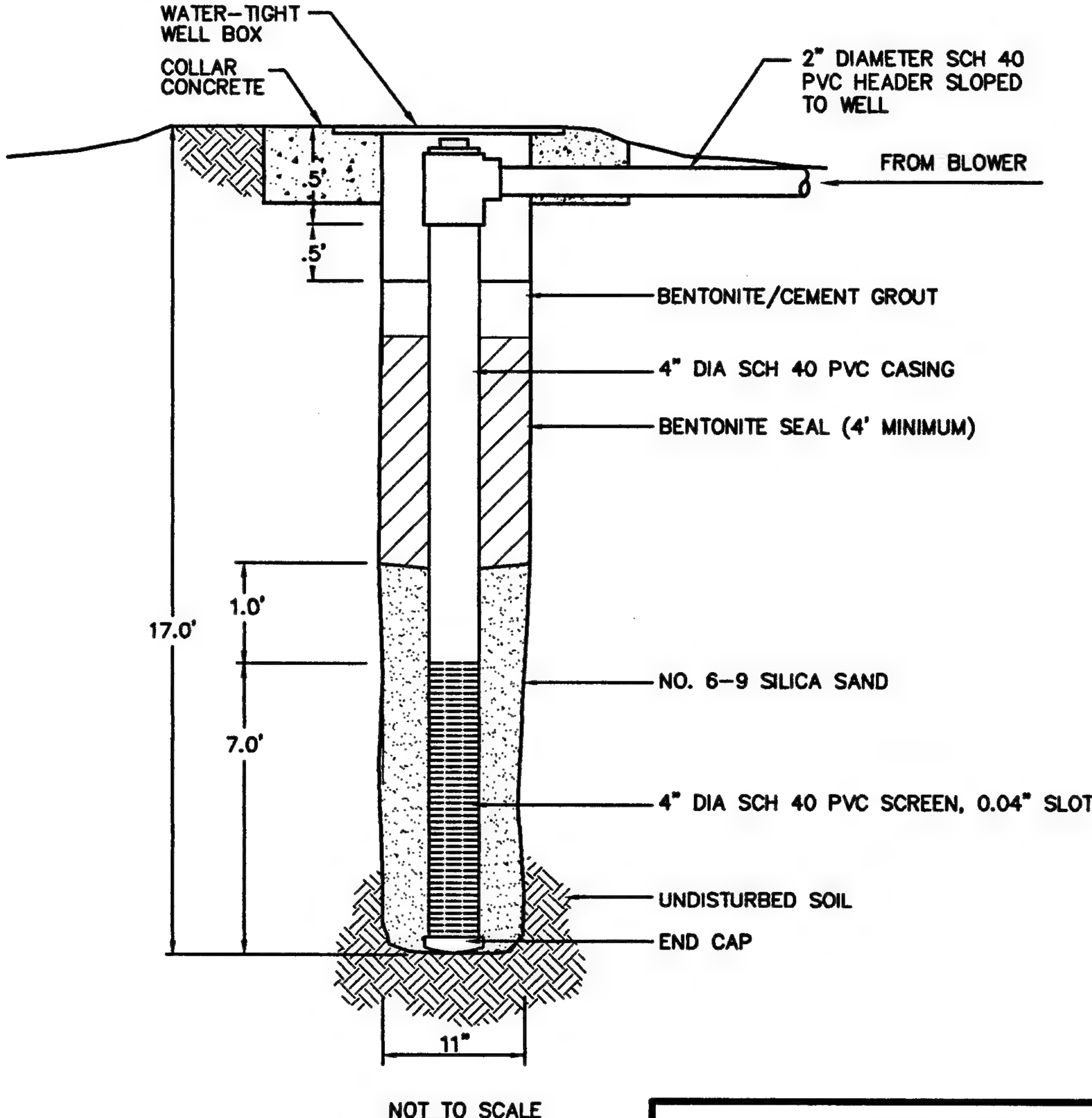


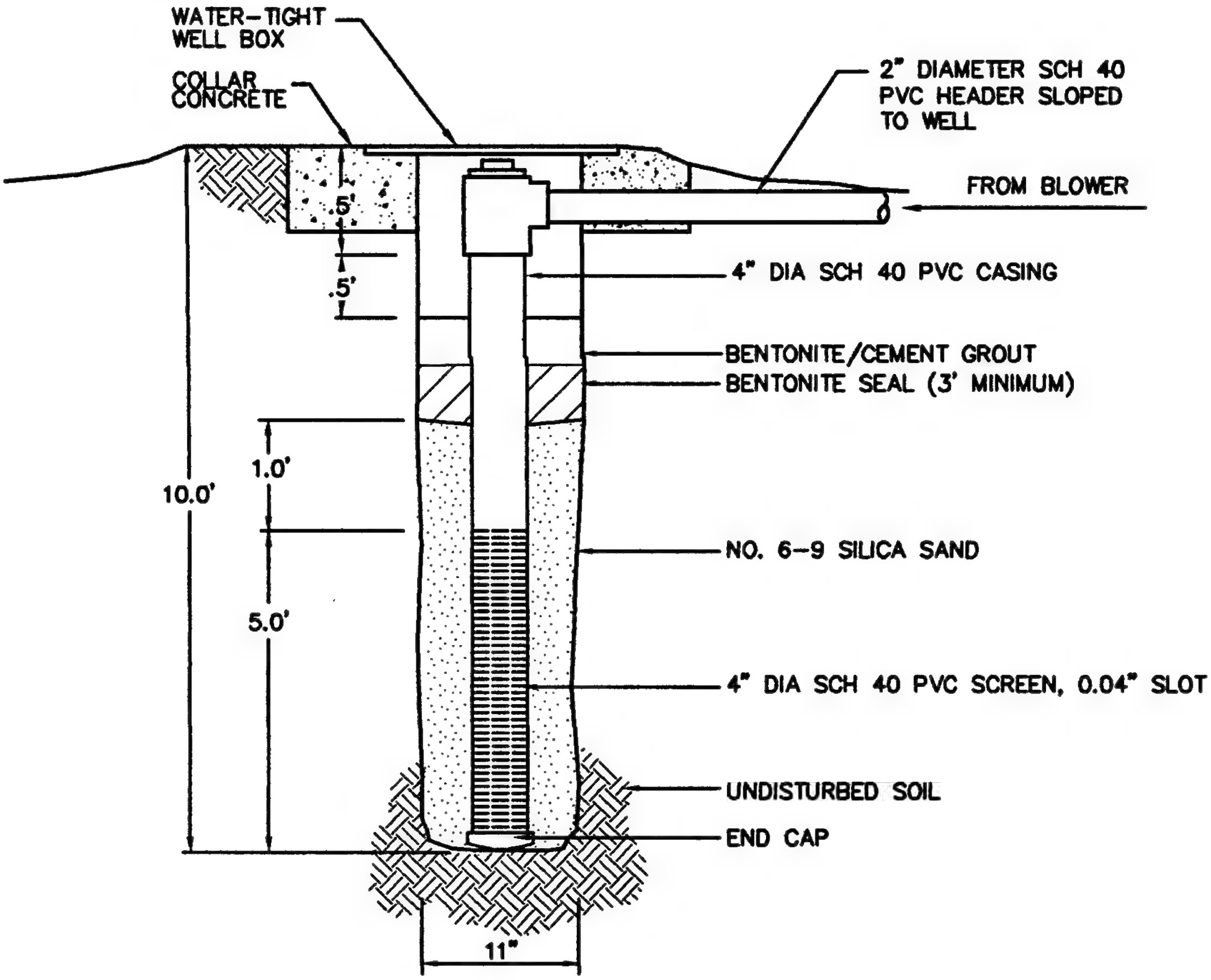
FIGURE 1.3A

AS-BUILT INJECTION VENT WELL NO. 1 CONSTRUCTION DETAIL AREA D

Ellsworth AFB, South Dakota

ENGINEERING-SCIENCE, INC.
Denver, Colorado

93DN0853, 10/28/93 at 14:00



NOT TO SCALE

FIGURE 1.3B

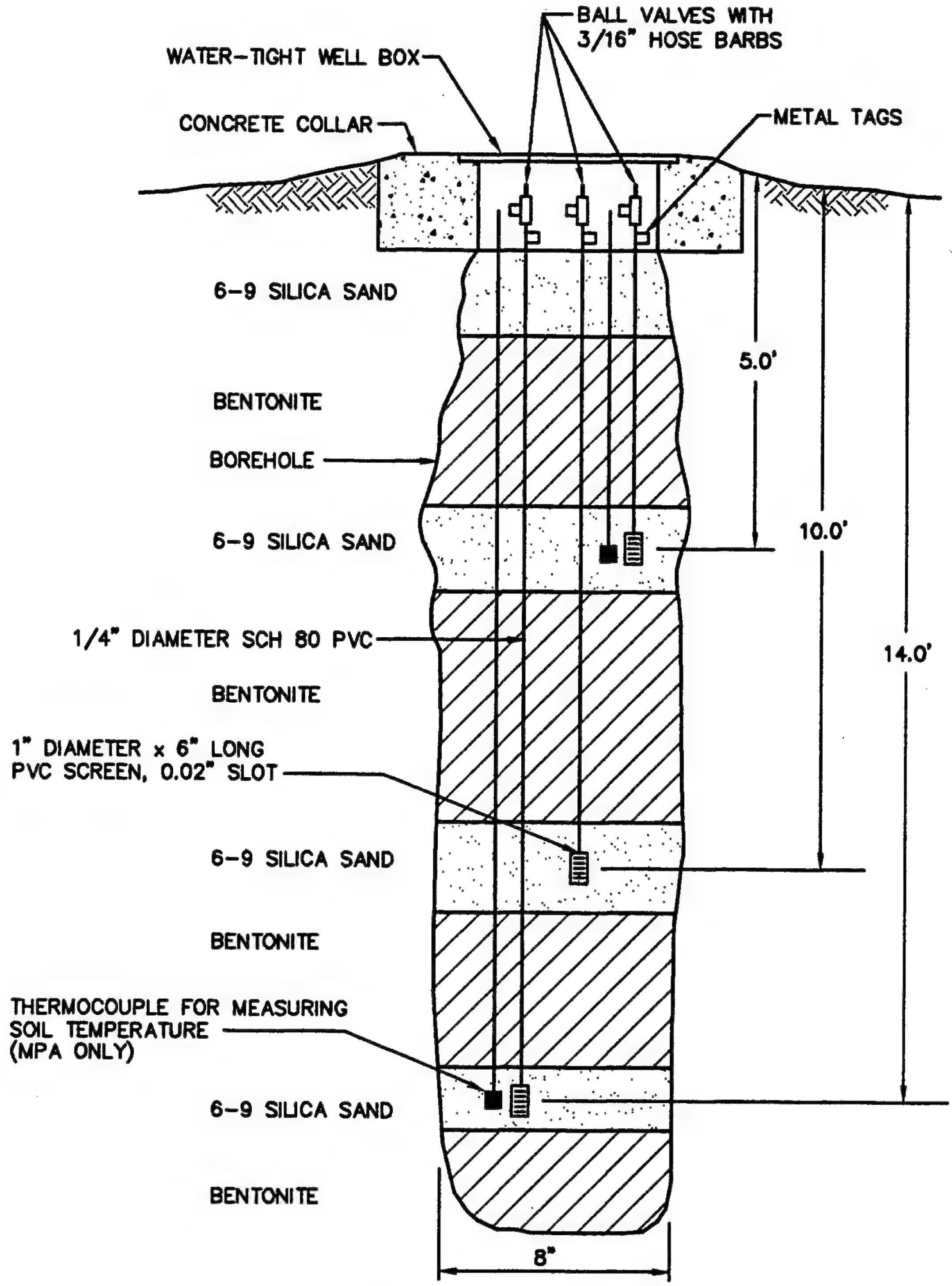
AS-BUILT INJECTION VENT WELL NO. 2 CONSTRUCTION DETAIL AREA D

Ellsworth AFB, South Dakota

ENGINEERING-SCIENCE, INC.
Denver, Colorado

ES

93DN0853, 10/28/93 at 14:00



NOT TO SCALE

FIGURE 1.4

TYPICAL AS-BUILT MONITORING POINT CONSTRUCTION DETAIL AREA D

Ellsworth AFB, South Dakota

ENGINEERING-SCIENCE, INC.
Denver, Colorado

ES

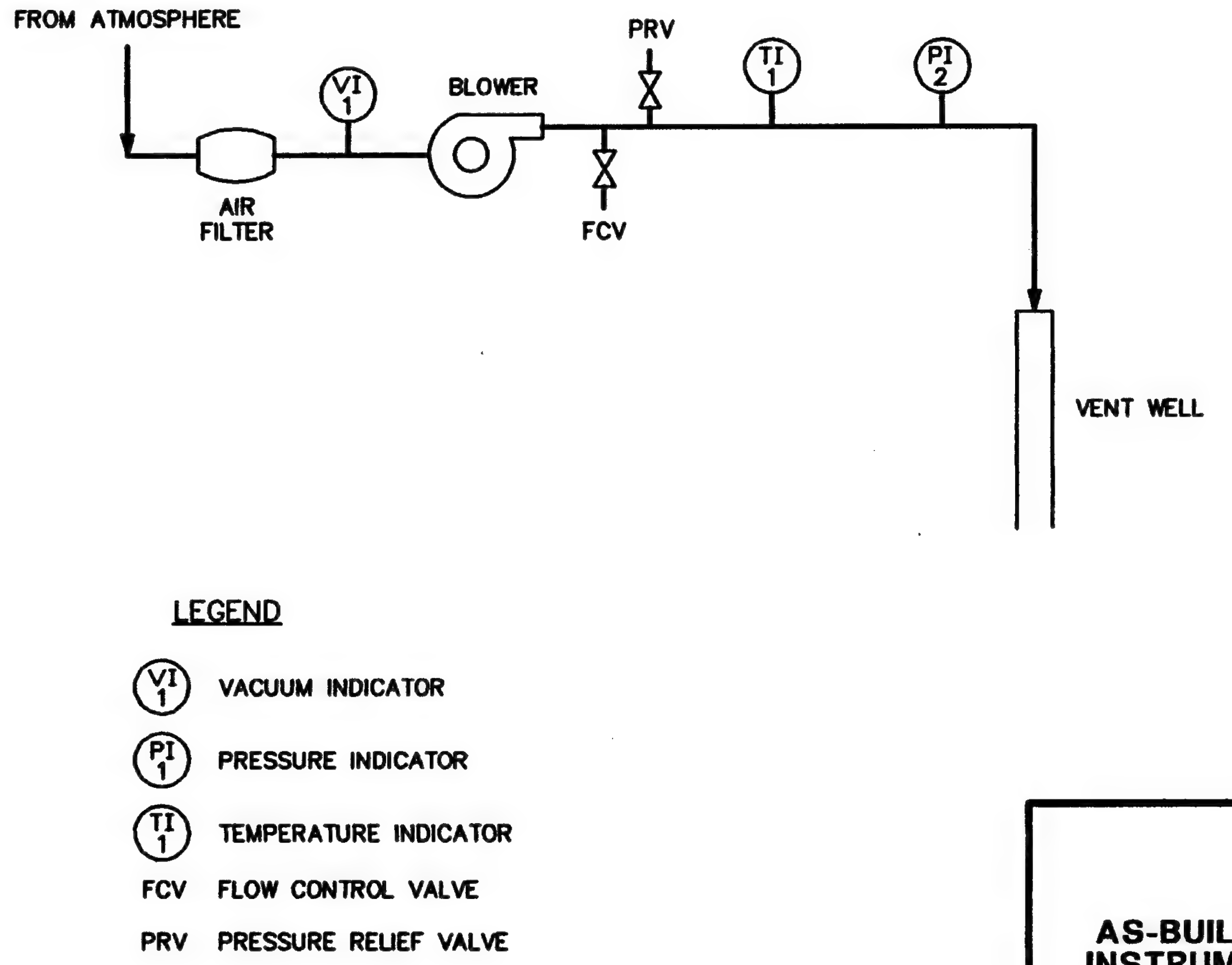


FIGURE 1.5

AS-BUILT BLOWER SYSTEM INSTRUMENTATION DIAGRAM FOR AIR INJECTION

AREA D

Ellsworth AFB, South Dakota

ENGINEERING–SCIENCE, INC.
Denver, Colorado

ES

93DN0565 10/28/93 at 15:51

maintenance manual to base personnel. A copy of the checklist is provided in Appendix B.

1.2 Building 102

One VW, three MPs, and a blower unit were installed at Building 102. Figures 1.6 and 1.7, respectively, depict the locations of and hydrogeologic cross section for the VW and MPs completed at the site. Boring logs for the MPs and VW are included in Appendix A. The background MP for this site was the existing groundwater monitoring well MW-24, located near the pilot test site at Area D.

1.2.1 Air Injection Vent Well

The air injection VW was installed following procedures described in the AFCEE bioventing protocol document (Hinchee et al., 1992). Figure 1.8 shows construction details for the VW. The VW was installed with the screened interval extending from 8 to 18 feet bgs. The groundwater surface at this site was approximately 17 feet bgs during the pilot test. The VW was constructed using 2-inch-diameter, schedule 40 PVC casing, with 10 feet of 0.04-inch slotted PVC screen. The annular space between the well casing and borehole was filled with 6-9 silica sand from the bottom of the borehole to approximately 1 foot above the well screen. Four feet of granular bentonite was placed above the sand, hydrated in place, and overlaid with a concrete seal to the existing concrete pavement surface. The top of the well was completed with a 2-inch-diameter PVC elbow.

1.2.2 Monitoring Points

The MP screens were installed at 10- and 15-foot depths. The three MPs (MPA, MPB, and MPC) at this site were constructed as shown in Figure 1.9. Each was constructed using 6-inch sections of 1-inch-diameter PVC well screen and 0.25-inch PVC riser pipes extending to the ground surface. At the top of each riser, a ball valve and a 3/16-inch hose barb were installed. The top of each MP was completed with a flush-mounted metal well protector set in concrete. Thermocouples were installed at the 10- and 15-foot depths at MPA to measure soil temperature variations.

1.2.3 Blower Unit

Due to the low injection pressures required at the site, a 1-horsepower Gast® regenerative blower unit was used for both the initial and extended pilot tests. For the initial pilot test the blower was energized by 208-volt, single-phase, 20-amp line power from a panel installed by Muth Electric, Inc. Power was brought to the panel from an existing panel in Building 102. The extended pilot test unit is hard-wired to a breaker in the newly installed panel. A relay and timer were also installed with the pilot test blower. The timer and relay are used to control the operating period of the blower. The blower is currently set to inject air twice a week for 9 hours at a time. Based on the measured microbial oxygen demand, this will assure adequate oxygenation of the contaminated soil while limiting the potential for volatile organic compound (VOC) vapor migration at the site. The 1-horsepower extended pilot test blower was configured to inject a nine-hour pulse of approximately 10 scfm for the extended pilot test. The configuration, instrumentation, and specifications for the initial pilot test and extended pilot test unit is shown on Figure 1.10. Prior to departing from the site, ES

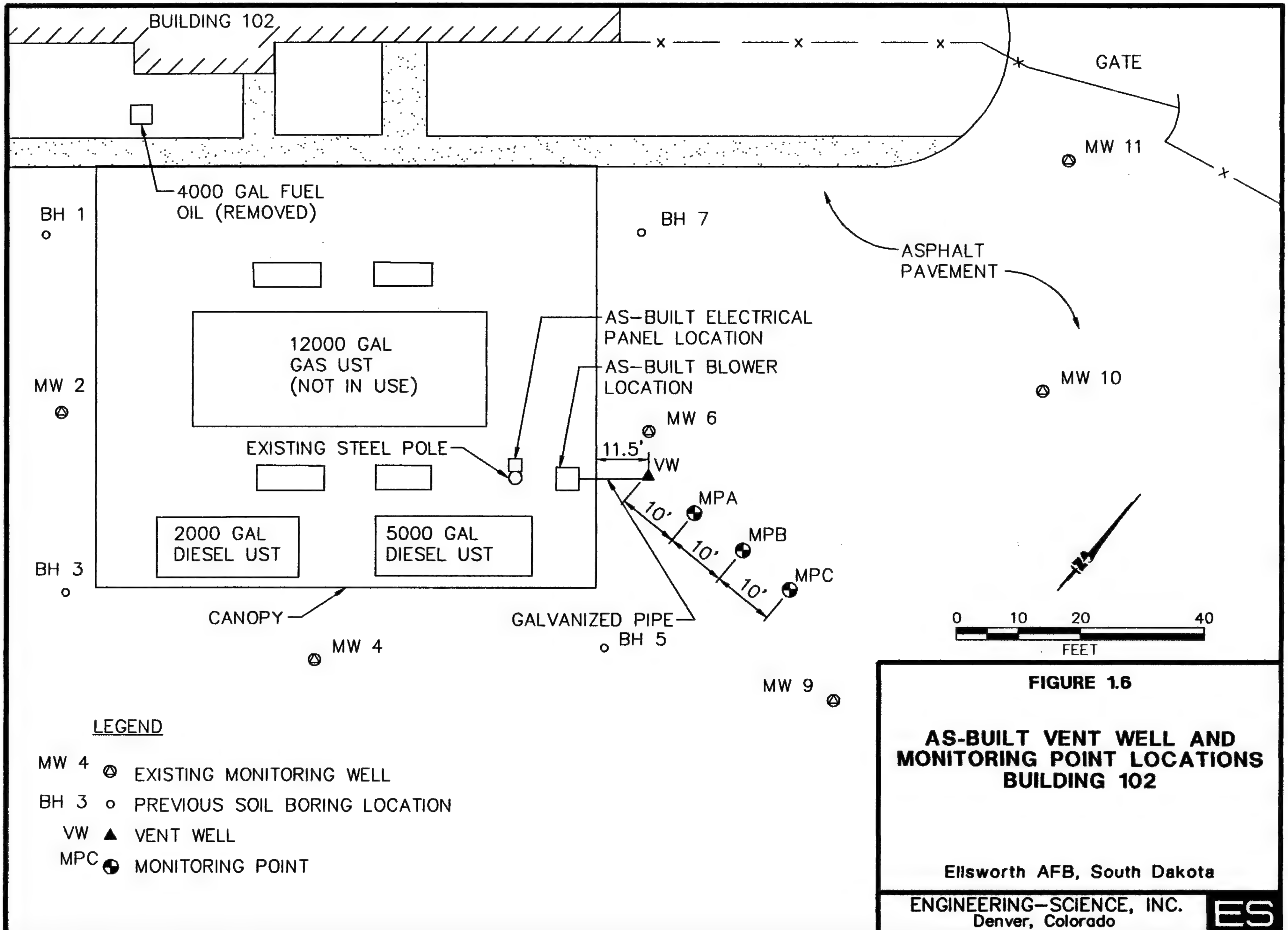


FIGURE 1.6

AS-BUILT VENT WELL AND MONITORING POINT LOCATIONS BUILDING 102

Ellsworth AFB, South Dakota

93DN1177, 10/28/93 at 14:58

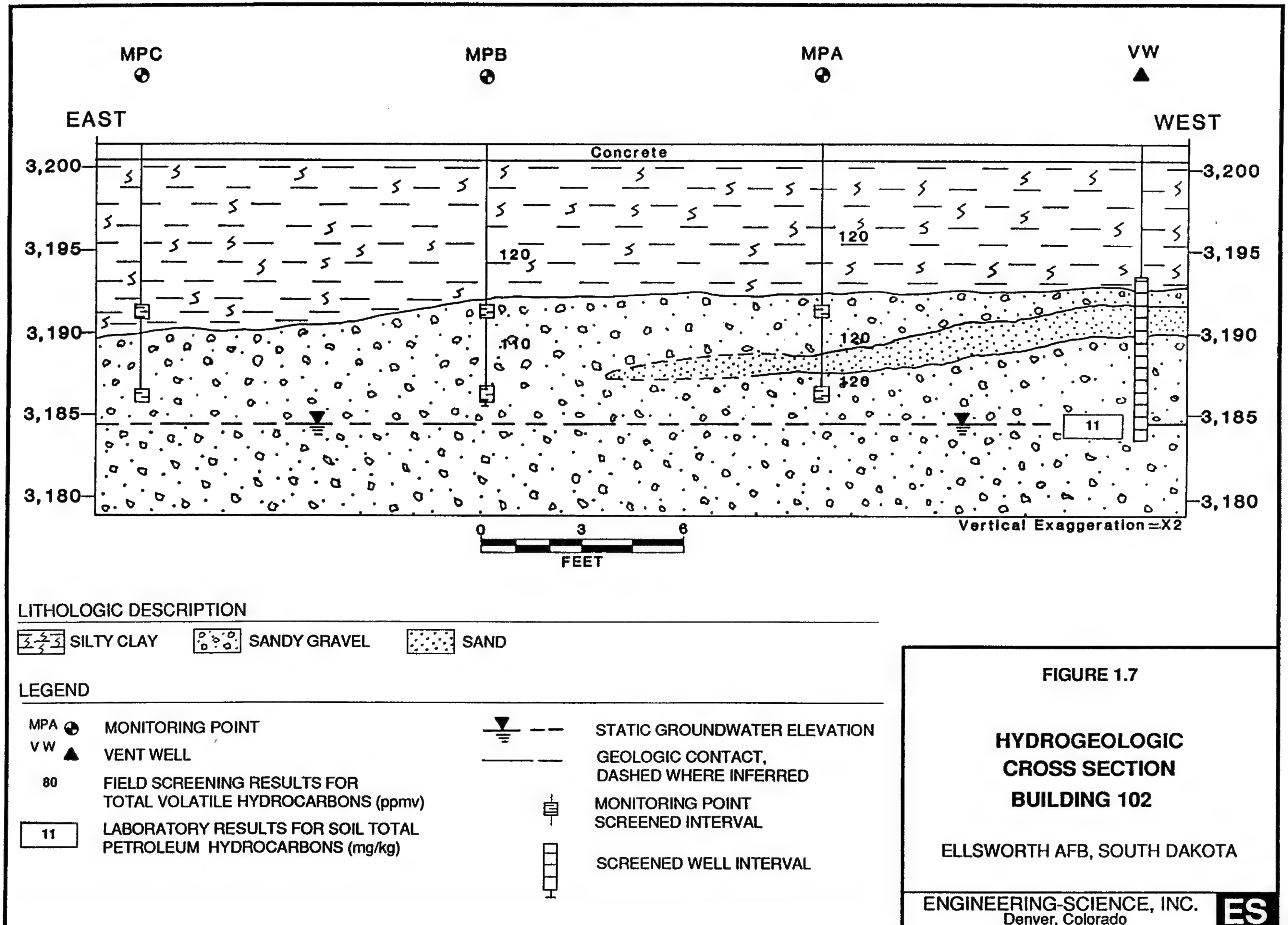


FIGURE 1.7

HYDROGEOLOGIC CROSS SECTION BUILDING 102

ELLSWORTH AFB, SOUTH DAKOTA

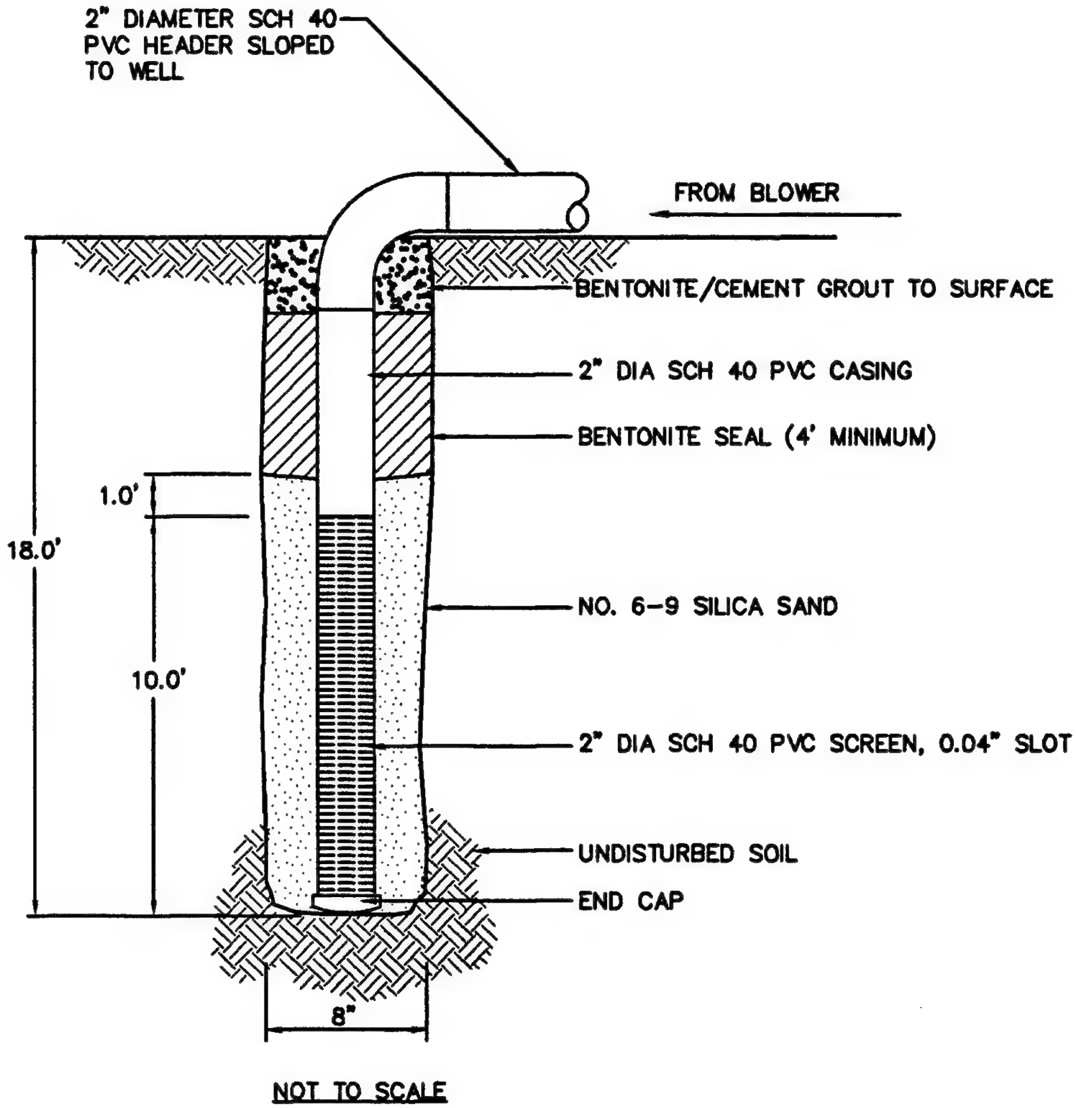


FIGURE 1.8

AS-BUILT
INJECTION VENT WELL
CONSTRUCTION DETAIL
BUILDING 102

Ellsworth AFB, South Dakota

ENGINEERING—SCIENCE, INC.
Denver, Colorado

ES

93DN0562, 10/28/93 at 15:16

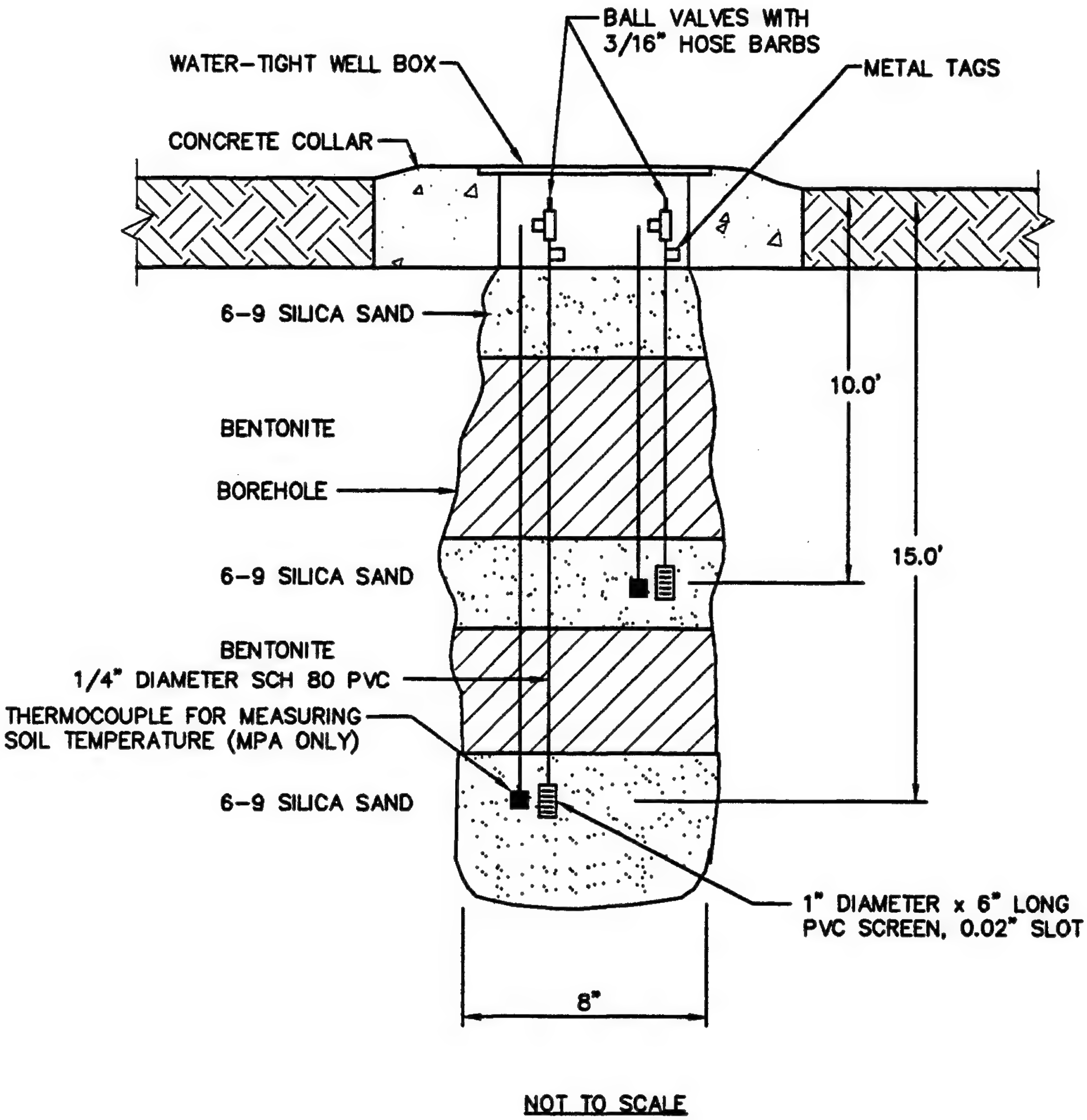


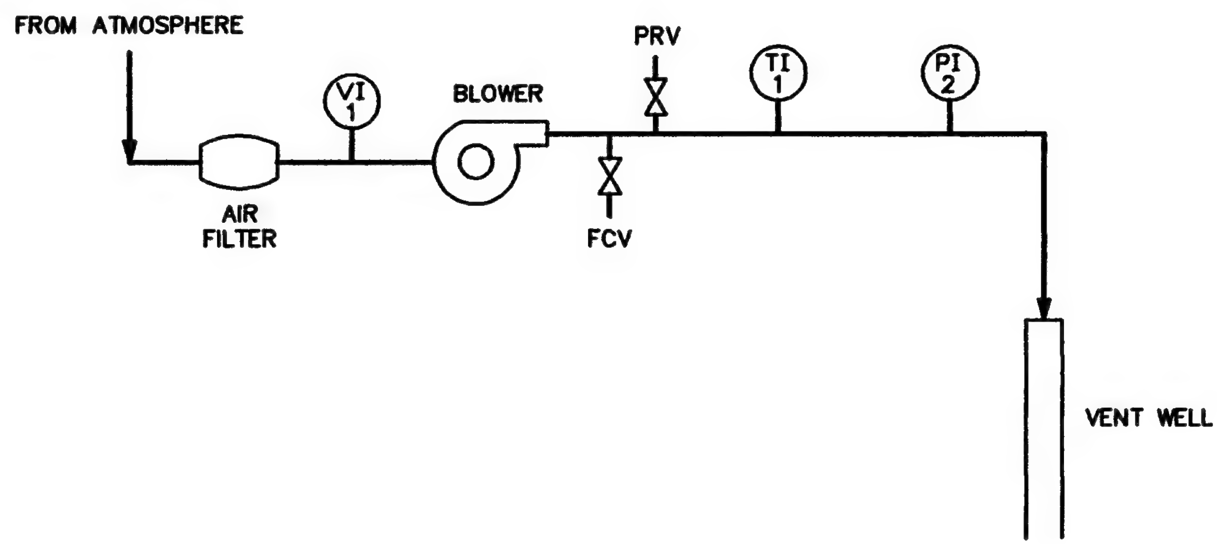
FIGURE 1.9

AS-BUILT MONITORING POINT CONSTRUCTION DETAIL BUILDING 102

Ellsworth AFB, South Dakota

ENGINEERING-SCIENCE, INC.
Denver, Colorado

93DN1176, 10/28/93 at 15:46



LEGEND

VI 1	VACUUM INDICATOR
PI 1	PRESSURE INDICATOR
TI 1	TEMPERATURE INDICATOR
FCV	FLOW CONTROL VALVE
PRV	PRESSURE RELIEF VALVE

FIGURE 1.10

AS-BUILT BLOWER SYSTEM INSTRUMENTATION DIAGRAM FOR AIR INJECTION

BUILDING 102

Ellsworth AFB, South Dakota

ENGINEERING–SCIENCE, INC.
Denver, Colorado

93DN0565, 10/28/93 at 14:51

engineers provided an O&M briefing checklist and blower maintenance manual to plant personnel. A copy of the checklist is provided in Appendix B.

2.0 PILOT TEST SOIL AND SOIL GAS SAMPLING RESULTS

2.1 Area D

2.1.1 Sampling Results

Soils at this site consist of silty clays overlying sands and gravels (Figure 1.2). Weathered shale bedrock was encountered approximately 19 feet bgs in the MPC borehole. The general soil profile consists of silty clay in the upper 10 feet bgs, sand to approximately 13 feet bgs, and gravel down to the weathered bedrock at approximately 19 feet bgs. Auger refusal in a coarse gravel was encountered at 17 feet bgs in the boring for VW1 at Area D. Groundwater was not encountered in the VWs at the site. Adjacent existing wells, however, indicated that groundwater was at approximately 15 feet bgs. The water-bearing formation is known to have a very long development time, and thus the groundwater surface may not have been immediately evident. Boring logs for the MPs and VWs are included in Appendix A.

Hydrocarbon contamination at this site appears to be confined within a zone extending from about 5 to 18 feet bgs. Contaminated soils were identified based on odor and headspace VOC field screening results. Contaminated soils were encountered in the VW and all MP boreholes, with the greatest contamination occurring in MPB. Soils at these locations had a strong hydrocarbon odor.

Soil samples for laboratory analysis were collected from split-spoon samplers with 1.5-inch-diameter brass liners. Soil sample headspace was screened for VOCs using a photoionization detector (PID) to determine the presence of contamination and to select soil samples for laboratory analysis. Soil samples for laboratory analysis were collected from a depth of 10 feet from MPA and MPB, and from a depth of 5 feet from VW1. A background soil sample was collected adjacent to the background well (MW-24) from a depth of 3 feet bgs. The background sample was collected from the bottom of a small pit and placed into a glass container with a Teflon® seal. Soil gas samples were collected by extracting soil gas from the completed VWs, and at depths of 14 feet from MPA and 10 feet from MPC.

Soil samples were shipped via Federal Express® to the Pace, Inc. laboratory in Novoto, California for chemical and physical analysis. Soil samples were analyzed for total recoverable petroleum hydrocarbons (TRPH); benzene, toluene, ethylbenzene and xylenes (BTEX); iron; alkalinity; total Kjeldahl nitrogen (TKN); and several physical parameters. The background soil sample was analyzed only for TKN. Soil gas samples were shipped via Federal Express® to Air Toxics, Inc. in Folsom, California for total volatile hydrocarbon (TVH) and BTEX analysis. The results of these analyses are provided in Table 2.1.

2.1.2 Exceptions To Test Protocol Document Procedures

Procedures described in the protocol document (Hinchee et al., 1992) were used to complete treatability tests at Area D. The only exception was that two VWs were installed at the site to reduce preferential air flow in the contaminated interval. Silty

TABLE 2.1
SOIL AND SOIL GAS ANALYTICAL RESULTS
AREA D
ELLSWORTH AFB, SOUTH DAKOTA

Analyte (Units)[a]	Sample Location-Depth (feet below ground surface)			
Soil Gas Hydrocarbons	VW1 10-17	VW2 5-10	MPA-14	MPC-10
TVH (ppmv)	58,000	650	68,000	13,000
Benzene (ppmv)	230	2.9	290	26
Toluene (ppmv)	18	ND[b]	22	11
Ethylbenzene (ppmv)	19	1.3	23	8.3
Xylenes (ppmv)	49	4.8	53	15
Soil Hydrocarbons	VW1-5	MPA-10	MPB-10	
TRPH (mg/kg)	840	3,310	4,340	
Benzene (mg/kg)	6.4	15	3.2	
Toluene (mg/kg)	13	10	3.7	
Ethylbenzene (mg/kg)	53	40	17	
Xylenes (mg/kg)	310	190	57	
Soil Inorganics	VW1-5	MPA-10	MPB-10	BG
Iron (mg/kg)	19,400	13,500	12,100	NS[c]
Alkalinity (mg/kg as $CaCO_3$)	2,070	760	620	NS
pH (units)	8.5	8.6	8.4	NS
TKN (mg/kg)	690	130	140	510
Phosphates (mg/kg)	480	520	490	NS
Soil Physical Parameters	VW1-5	MPA-10	MPB-10	
Moisture (% wt.)	2.3	13	17	
Gravel (%)	0.1	0.6	0	
Sand (%)	12.9	34.5	23.4	
Silt (%)	47.0	35.3	44.7	
Clay (%)	39.9	29.6	31.9	
Soil Temperature (°F)	MPA-14	MPA-14		
	61.7	52.7		

a/ mg/kg=milligrams per kilogram, ppmv=parts per million, volume per volume; $CaCO_3$=Calcium carbonate; TKN=total Kjeldahl nitrogen; TVH=total volatile hydrocarbons; TRPH=total recoverable petroleum hydrocarbons; °F = degrees Fahrenheit

b/ ND=not detected.

c/ NS=not sampled

d/ BG=background sample

clay was found at Area D to depths of approximately 10 feet bgs. Sands and gravels were found below this clay. To avoid having the majority of the injected air flow through the more permeable sand and gravel, two wells were installed with screens located at different depths. One well was screened entirely within the clay layer. The other well, placed approximately 3 feet away, was screened entirely within the more permeable layer below. A valve was used to balance flow so that an equal amount of air was flowing into each interval. A single blower provides air to both VWs.

2.2 Building 102

2.2.1 Sampling Results

Soils at this site consist primarily of silty clays overlying gravel (Figure 1.7). A seam of sand was encountered in the gravel at approximately 11 feet bgs in the boreholes for MPA and the VW. Bedrock was not encountered during drilling for this pilot test and is not shown in the figure. Groundwater was not encountered in the VW at the site. Adjacent existing wells, however, indicated that groundwater was at approximately 17 feet bgs. The water-bearing formation is known to have a very long development time, and thus the groundwater surface may not have been immediately evident. The entire site is covered with approximately 12 inches of concrete pavement. Boring logs for the MPs and VW are included in Appendix A.

Hydrocarbon contamination at this site occurs within a narrow zone immediately above the groundwater surface. Contaminated soils were identified based on odor and headspace VOC field screening results. Soil samples for field screening were collected off of the augers; gravel and cobbles at the site did not allow the use of a split-spoon sampler. Contaminated soils were encountered in the VW and all MP boreholes. Soils removed from the bottoms of these boreholes had a noticeable hydrocarbon odor. Little contamination was detected in soils located above the groundwater surface.

A soil sample for laboratory analysis was collected from the augers used to drill the VW. Split-spoon samplers could not be used at the site due to the large amount of gravel and cobbles in the soil. The soil sample headspace was screened for VOCs using a PID to determine the presence of contamination and to determine if the sample should be sent for laboratory analysis. The sample was collected from the bottom of the augers, and is assumed to have come from approximately 16 feet bgs. Soil gas samples were collected by extracting soil gas from the completed VW, and from a depth of 15 feet at MPA and MPC. Concentrations of soil contaminants appear to be lower than expected when compared to soil gas contaminant concentrations. Matrix interference appears to be a probable cause for the low contaminant levels detected in soil. The majority of the sample sent to the laboratory consisted of gravel, which causes low contaminant recovery during laboratory analysis.

Soil samples were shipped via Federal Express® to the Pace, Inc. laboratory for chemical and physical analysis. Soil samples from the MPs were analyzed for TRPH, BTEX, iron, alkalinity, TKN, and several physical parameters. Soil gas samples were shipped via Federal Express® to Air Toxics, Inc. in Folsom, California for TVH and BTEX analysis. The results of these analyses are provided in Table 2.2.

TABLE 2.2

SOIL AND SOIL GAS ANALYTICAL RESULTS

BUILDING 102

ELLSWORTH AFB, SOUTH DAKOTA

Analyte (Units)[a/]	Sample Location-Depth (feet below ground surface)		
Soil Gas Hydrocarbons	VW 8-18	MPA-15	MPC-15
TVH (ppmv)	67,000	73,000	97,000
Benzene (ppmv)	340	230	400
Toluene (ppmv)	42	27	75
Ethylbenzene (ppmv)	8.4	3.4	8.3
Xylenes (ppmv)	45	24	48
Soil Hydrocarbons	VW-16		
TRPH (mg/kg)	11		
Benzene (mg/kg)	0.18		
Toluene (mg/kg)	0.60		
Ethylbenzene (mg/kg)	0.78		
Xylenes (mg/kg)	4.3		
Soil Inorganics	VW-16		
Iron (mg/kg)	36,800		
Alkalinity (mg/kg as $CaCO_3$)	640		
pH (units)	8.6		
TKN (mg/kg)	24		
Phosphates (mg/kg)	1,000		
Soil Physical Parameters	VW-16		
Moisture (% wt.)	7.2		
Gravel (%)	45.6		
Sand (%)	40.0		
Silt (%)	9.0		
Clay (%)	5.4		
Soil Temperature (°F)	MPA-10	MPA-15	
	57.8	54.5	

a/ mg/kg=milligrams per kilogram, ppmv=parts per million, volume per volume; $CaCO_3$=Calcium carbonate; TKN=total Kjeldahl nitrogen; TVH=total volatile hydrocarbons; TRPH=total recoverable petroleum hydrocarbons; °F=degree Fahrenheit

2.2.2 Exceptions To Test Protocol Document Procedures

Procedures described in the protocol document (Hinchee et al., 1992) were used to complete treatability tests at Building 102 with two exceptions. Only one soil sample was collected due to extensive amounts of gravel and cobbles in the soil at the site. The sample was collected from cuttings on the augers when it was determined that a sampling device could not adequately penetrate gravels at the site. The injection well was constructed using 2-inch diameter PVC when it was determined that the larger augers needed to construct a 4-inch well would not penetrate the cobbles and gravel at Building 102.

3.0 PILOT TEST RESULTS

3.1 Area D

3.1.1 Initial Soil Gas Chemistry

Prior to initiating any air injection, all MPs were purged until oxygen levels had stabilized, and initial oxygen, carbon dioxide, and TVH concentrations were sampled using portable gas analyzers, as described in the technical protocol document (Hinchee et al., 1992). At VW1, all 14-foot MP intervals, and two of the 10-foot MP screened intervals, microorganisms had depleted soil gas oxygen supplies, indicating significant biological activity and soil contamination. Table 3.1 summarizes the initial soil gas chemistry.

3.1.2 Air Permeability

An air permeability test was conducted according to protocol document procedures. Air was injected into VW1 for 1.2 hours at a rate of approximately 15 scfm and an average pressure of 2.2 pounds per square inch (psi). The maximum pressure response at each MP is listed in Table 3.2. The pressure measured at the MPs gradually increased at an irregular rate throughout the period of air injection. Due to the irregular pressure response, the steady-state method of determining air permeability was selected. A soil gas permeability value of 1.3 darcys, typical for a sandy-silt, was calculated for this site. A radius of pressure influence of at least 25 feet was observed at the 10- and 14-foot depths.

3.1.3 Oxygen Influence

The depth and radius of oxygen increase in the subsurface resulting from air injection period into VW1 during pilot testing is the primary design parameter for full-scale bioventing systems. Optimization of full-scale and multiple VW systems requires pilot testing to determine the volume of soil that can be oxygenated at a given flow rate and VW screen configuration.

Table 3.3 presents the change in soil gas oxygen levels that occurred during a 18-hour injection period using the initial pilot test blower, and during a 41-hour period of injection using the extended pilot test blower unit. These periods of air injection produced changes in soil gas oxygen levels at the 10- and 14-foot screened intervals. Based on measured changes in oxygen levels, it is anticipated that the radius of influence for a long-term bioventing system at this site will exceed 25 feet at depths

TABLE 3.1

INITIAL SOIL GAS CHEMISTRY

AREA D

ELLSWORTH AFB, SOUTH DAKOTA

Sample Location	Depth (ft)	O_2 (%)	CO_2 (%)	Field TVH (ppmv)[a]	Lab TVH (ppmv)[b]	Soil TRPH (mg/kg)[c]
MPA	5	17.0	5.0	1100	NS	NS[d]
MPB	5	19.1	2.3	920	NS	NS
MPC	5	17.0	1.0	1000	NS	NS
MPA	10	1.0	3.8	1800	NS	3,310
MPB	10	19.2	0.6	1200	NS	4,340
MPC	10	1.5	11.2	3400	13,000	NS
MPA	14	0.5	5.0	1200	68,000	NS
MPB	14	0.0	8.0	1000	NS	NS
MPC	14	0.5	8.8	1000	NS	NS
VW1	10-17	1.5	4.0	3400	58,000	804[c]
VW2	5-10	20.1	1.2	540	650	NS

a/ Field screening results, in parts per million, volume per volume (ppmv).
b/ Laboratory results.
c/ Laboratory soil results, in milligrams per kilogram (mg/kg).
d/ NS=not sampled.
e/ Sample collected from 5 feet bgs.

TABLE 3.2

MAXIMUM PRESSURE RESPONSE

AIR PERMEABILITY TEST

AREA D

ELLSWORTH AFB, SOUTH DAKOTA

	Distance from injection well (VW) (feet)								
	5 (MPA)			15 (MPB)			25 (MPC)		
Depth (feet)	5	10	14	5	10	14	5	10	14
Time (min)	10	4	6	60	1	6	2	2	9
Max Press. (inches H_2O)	0[a/]	5.9	7.0	0.05	0.1	4.0	0.10	0.25	1.95

[a/] Point short circuited to the atmosphere

TABLE 3.3
INFLUENCE OF AIR INJECTION AT VENT WELL ON MONITORING POINT OXYGEN LEVELS
AREA D
ELLSWORTH AFB, SOUTH DAKOTA

MP	Distance From VW (ft)	Depth(ft)	Initial O_2(%)	Final O_2(%)	
				Permeability Test[a/]	Long-term System[b/]
A	5	5	17.0	16.0	NS[c/]
B	15	5	19.1	19.5	NS
C	25	5	17.0	21.0	NS
A	5	10	1.0	11.0	NS
B	15	10	19.2	19.2	NS
C	25	10	1.5	20.7	NS
A	5	14	0.5	20.4	NS
B	15	14	0.0	18.5	NS
C	25	14	0.5	4.5	7.5

a/ Reading taken at end of 18-hour air permeability test.
b/ Reading taken after approximately 41 hours of injection using long-term blower system.
c/ NS = not sampled.

below 10 feet bgs. Monitoring during the extended pilot test at this site will better define the effective treatment radius.

3.1.4 In Situ Respiration Rates

The *in situ* respiration test was performed by injecting a mixture of air (oxygen) and approximately 1.5 percent helium (inert tracer gas) into four MP screened intervals (MPA-14, MPB-14, MPC-10, and VW1) for a 22-hour period. Oxygen loss and other changes in soil gas composition over time were then measured at these intervals and all other MP intervals which had elevated oxygen levels following the air permeability test. Oxygen, TVH, carbon dioxide, and helium were measured for a period of approximately 24 hours following air injection. The measured oxygen losses were then used to calculate biological oxygen utilization rates. Oxygen levels at MPC-10 did not decrease and the point was abandoned for use in the respiration test. The results of *in situ* respiration testing for selected MP intervals at this site are presented in Figures 3.1 through 3.4. Table 3.4 provides a summary of the oxygen utilization rates.

Because helium is a conservative, inert gas, the change in helium concentrations over time can be useful in determining the effectiveness of the bentonite seals between MP screened intervals. Figures 3.1 through 3.4 compare oxygen utilization and helium retention. Because the observed helium loss was negligible, and because helium will diffuse approximately three times faster than oxygen due to oxygen's greater molecular weight, the measured oxygen loss is the result of bacterial respiration and not due to faulty MP construction.

Results from this test indicate significant soil contamination only in the deeper soils beneath the silty clay layer. All 5-foot MP intervals initially had elevated levels of oxygen, indicating little microbial activity and associated contamination. The soil gas sample taken from VW2, which is screened from 5 to 10 feet bgs, contained concentrations of contaminants that were orders of magnitude smaller than a similar sample taken from 10 to 17 feet bgs in VW1 (Table 3.1). VW2 was installed in an attempt to remediate soil in the 5- to 10-foot interval that had been characterized as contaminated by previous studies. Refer to Section 2.1.3 of Part I of this document for more information on site contaminants.

Oxygen loss occurred at extremely high rates, ranging from 0.01669 percent per minute at VW1 to 0.01986 percent per minute at MPA-10. At MPA-10, the oxygen dropped from 19.0 percent to 9.0 percent in 500 minutes.

Based on these oxygen utilization rates, an estimated 1,510 to 2,720 milligrams (mg) of fuel per kilogram (kg) of soil can be degraded each year at this site. This conservative estimate is based on an average air-filled porosity of approximately 0.068 liter per kg of soil, and a ratio of 3.5 mg of oxygen consumed for every 1 mg of fuel biodegraded. Actual degradation rates may exceed these estimates.

3.1.5 Potential Air Emissions

The long-term potential for air emissions from full-scale bioventing operations at this site is low because of the low-permeability, near-surface clay soil overlying sand and gravel. Emissions should be minimal because accumulated vapors will move

Figure 3.1
Respiration Test
Area D: MPA-10
Ellsworth AFB, SD

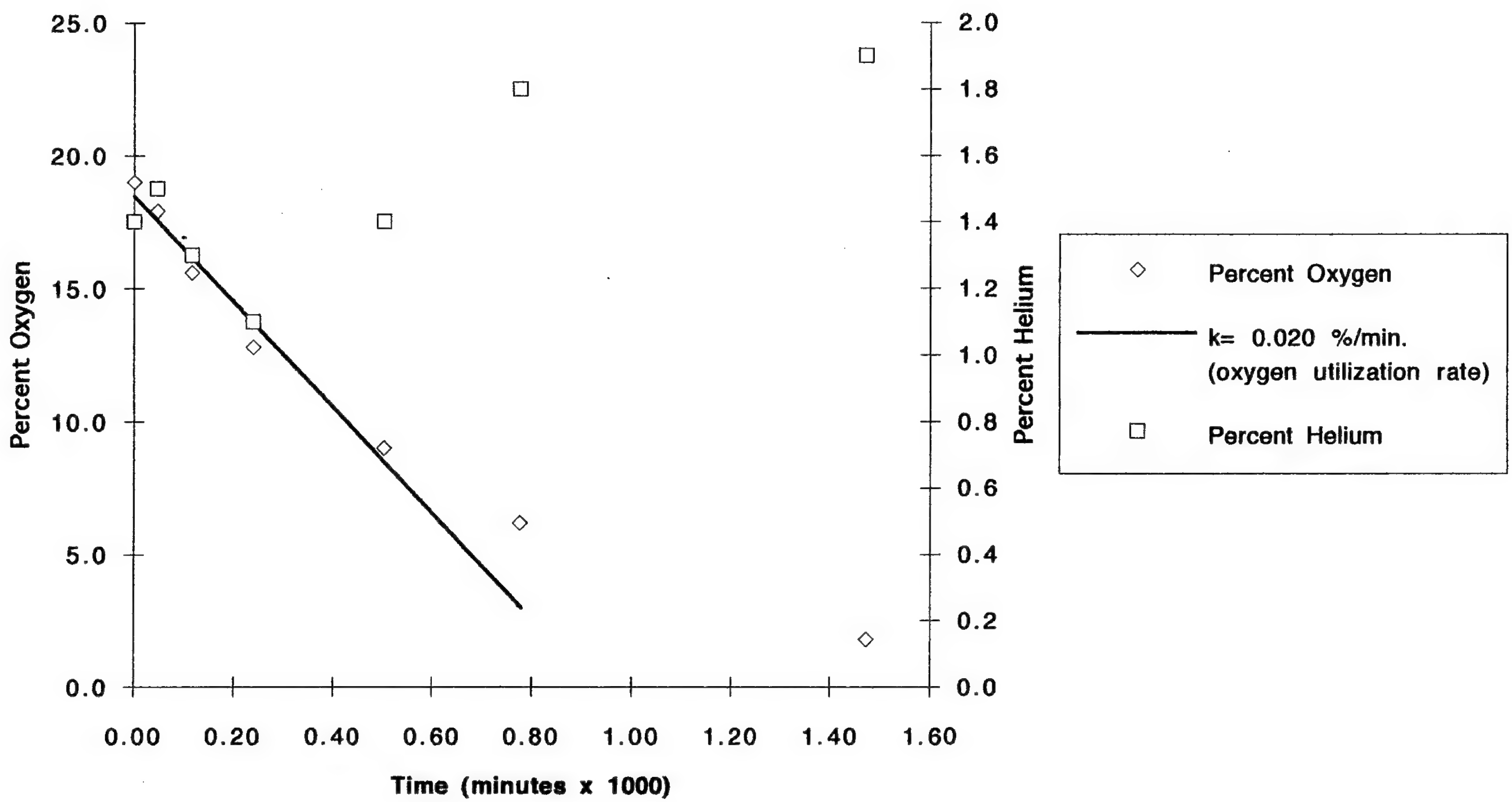


Figure 3.2
Respiration Test
Area D: MPA-14
Ellsworth AFB, SD

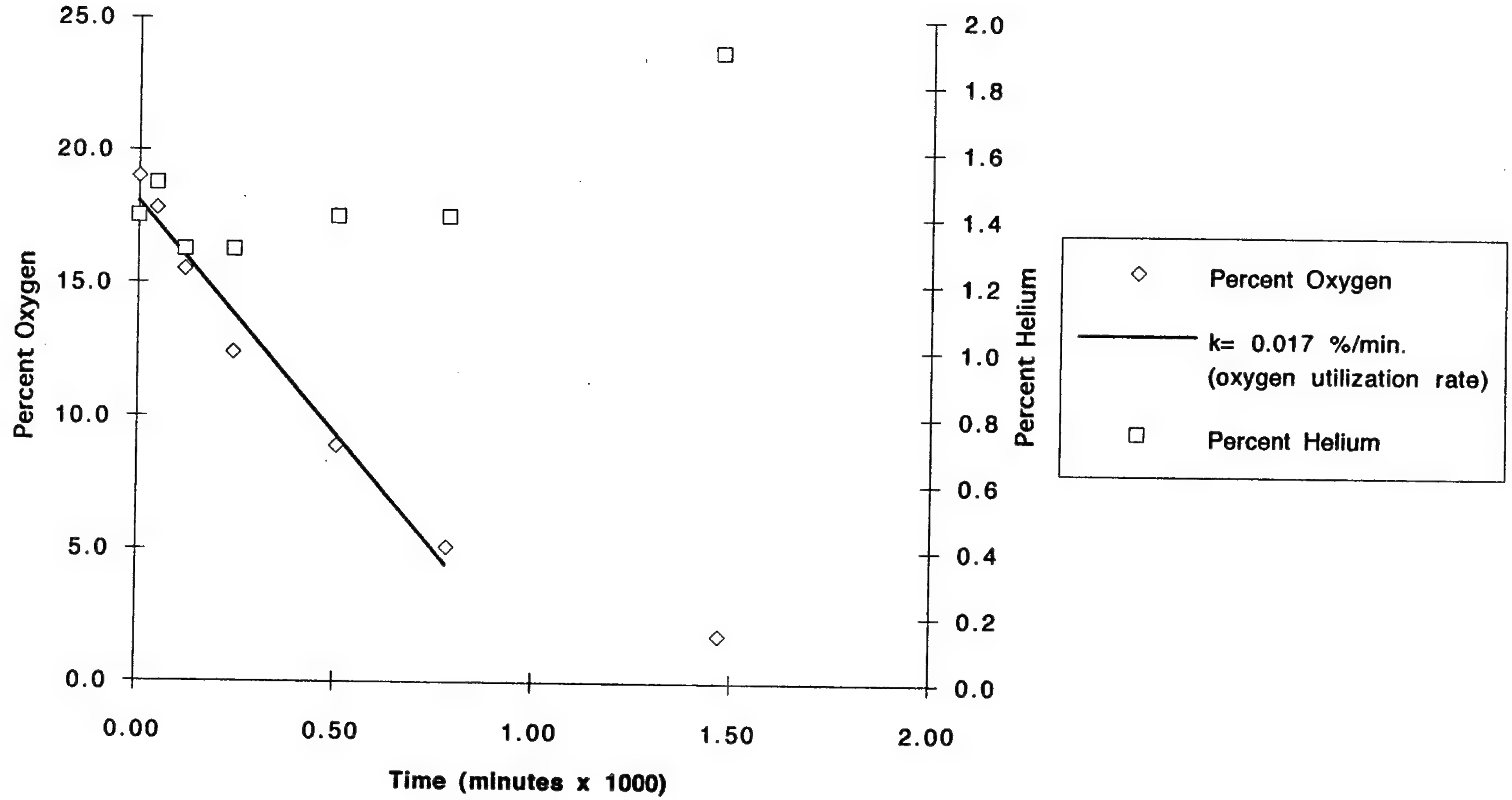


Figure 3.3
Respiration Test
Area D: MPB-14
Ellsworth AFB, SD

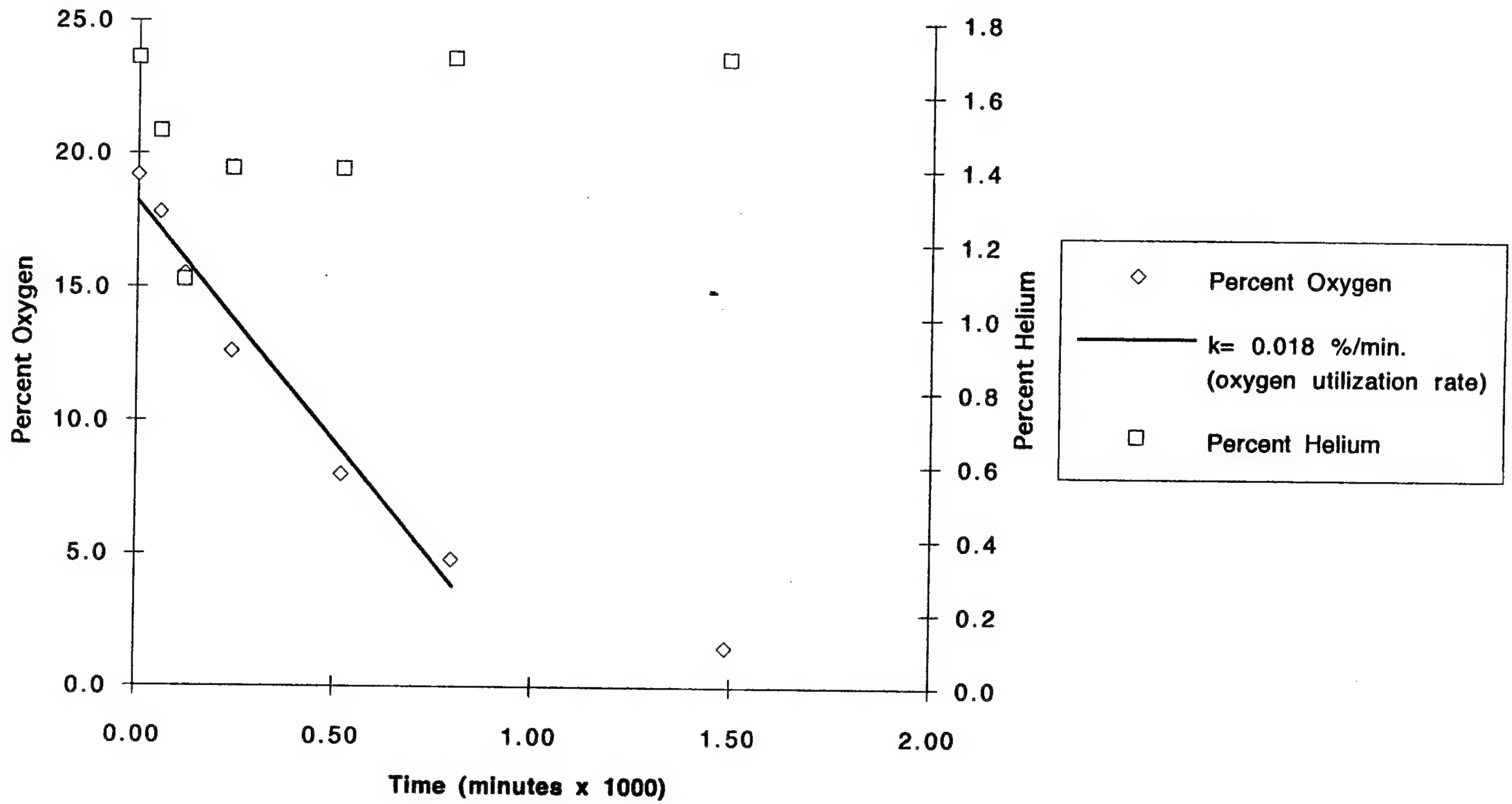


Figure 3.4
Respiration Test
Area D: VW-1
Ellsworth AFB, SD

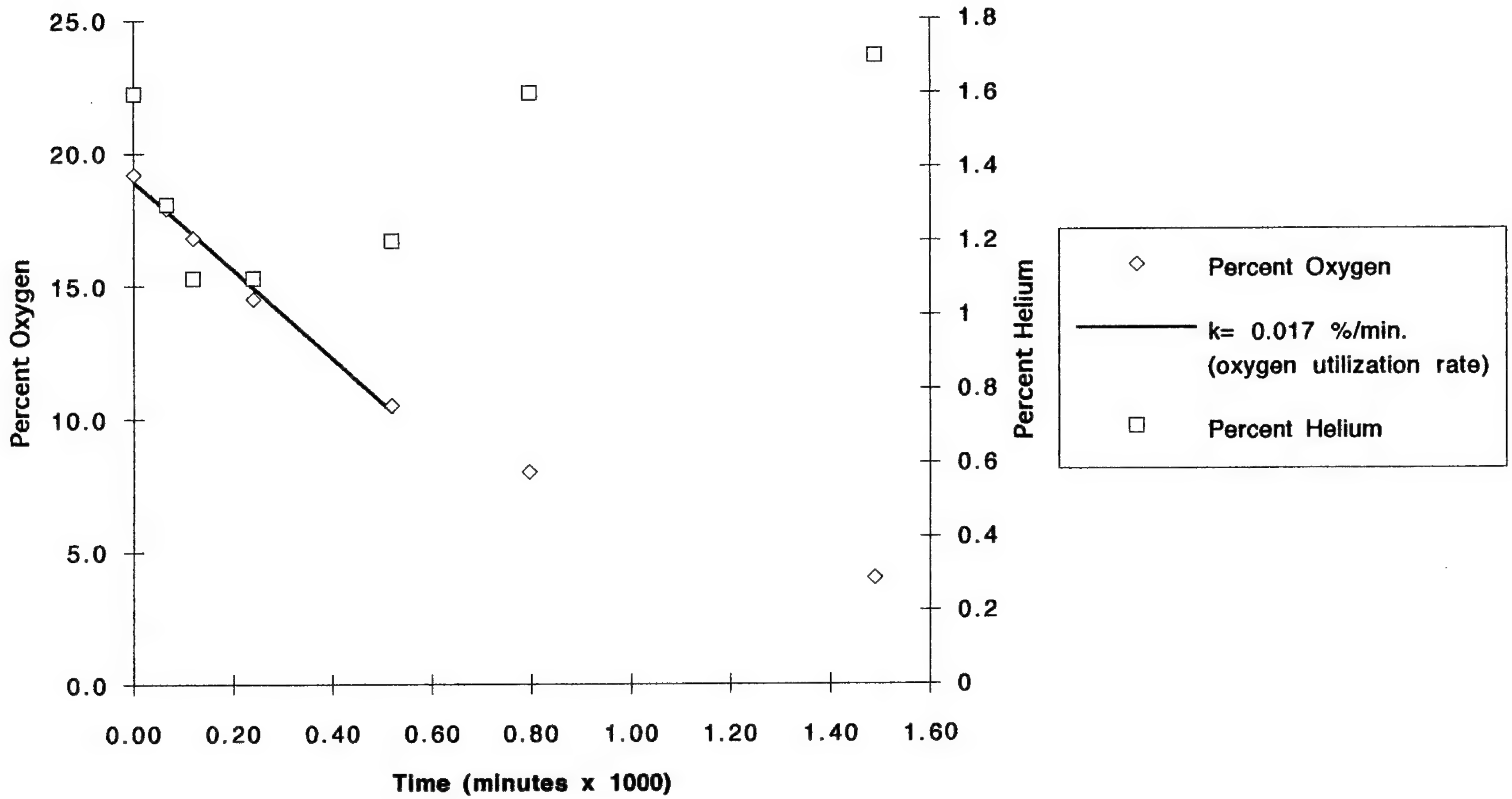


TABLE 3.4
OXYGEN UTILIZATION RATES
AREA D
ELLSWORTH AFB, SOUTH DAKOTA

Location	O_2 Loss[a/] (%)	Test[b/] Duration (min)	O_2 Utilization[c/] Rate (%/min)
MPA-10	10.0	500	0.020
MPA-14	13.9	780	0.017
MPB-14	14.4	800	0.018
VW1	8.7	520	0.017

a/ Actual measured oxygen loss.

b/ Elapsed time from beginning of test to time when minimum oxygen concentration was measured.

c/ Values based on best-fit lines (Figures 3.1 through 3.4).

slowly outward from the air injection VWs and will be biodegraded as they move horizontally through the soil.

3.2 Building 102

3.2.1 Initial Soil Gas Chemistry

Prior to initiating any air injection, all MPs were purged until oxygen levels had stabilized, and initial oxygen, carbon dioxide, and TVH concentrations were sampled using portable gas analyzers, as described in the technical protocol document (Hinchee et al., 1992). At all MP screened intervals and at the VW, microorganisms had depleted soil gas oxygen supplies, indicating significant soil contamination. A sample could not be extracted from point MPB-15, and this point was consequently abandoned. Table 3.5 summarizes the initial soil gas chemistry.

3.2.2 Air Permeability

An air permeability test was conducted according to protocol document procedures. Air was injected into the VW for 1 hour at a rate of approximately 40 scfm and an average pressure of 28 inches of water. The maximum pressure response at each MP is presented in Table 3.6. The pressure measured at the MPs increased irregularly during the period of air injection. Due to the irregular pressure response, the steady-state method of determining air permeability was selected. A soil gas permeability value of 14 darcys, typical for gravel and loose sands, was calculated for this site. A radius of pressure influence of at least 30 feet was observed at all MP depths.

3.2.3 Oxygen Influence

The depth and radius of oxygen increase in the subsurface resulting from air injection into the central VW during pilot testing is the primary design parameter for full-scale bioventing systems. Optimization of full-scale and multiple VW systems requires pilot testing to determine the volume of soil that can be oxygenated at a given flow rate and VW screen configuration.

Table 3.7 presents the change in soil gas oxygen levels that occurred during a 15-hour period of injection using the extended pilot test blower unit. This period of air injection at approximately 10 scfm produced changes in soil gas oxygen levels at all MP screened intervals. Based on measured changes in oxygen levels, it is anticipated that the radius of influence for a long-term bioventing system at this site will exceed 30 feet at all depths. Monitoring during the extended pilot test at this site will better define the effective treatment radius.

3.2.4 In Situ Respiration Rates

The *in situ* respiration test was performed by injecting a mixture of air (oxygen) and approximately 1.5 percent helium (inert tracer gas) into three MP screened intervals (MPA-15, MPB-10, and MPC-15) and the VW for a 19-hour period. Oxygen loss and other changes in soil gas composition over time were then measured at these intervals and at two additional points (MPA-10 and MPC-10) that had elevated oxygen levels following air injection. Oxygen, TVH, carbon dioxide, and helium were measured for a period of 47 hours following air injection. The measured oxygen loss was then used to calculate the biological oxygen utilization rate. The results of *in situ* respiration

TABLE 3.5
INITIAL SOIL GAS CHEMISTRY
BUILDINNG 102
ELLSWORTH AFB, SOUTH DAKOTA

Sample Location	Depth (ft)	O_2 (%)	CO_2 (%)	Field TVH (ppmv)[a/]	Lab TVH (ppmv)[b/]	Soil TRPH (mg/kg)[c/]
MPA	10	4.1	2.5	6,000	NS[d/]	NS
MPB	10	3.1	4.1	6,000	NS	NS
MPC	10	0.6	5.2	6,400	97,000	NS
MPA	15	3.5	3.8	6,200	73,000	NS
MPB	15	NS	NS	NS	NS	NS
MPC	15	0.5	5.0	1,900	NS	NS
VW	8-18	1.9	7.0	4,100	67,000	11[e/]

a/ Field screening results, in parts per million, volume per volume (ppmv).
b/ Laboratory results.
c/ Laboratory soil results, in milligrams per kilogram (mg/kg).
d/ NS=not sampled.
e/ Sample collected from approximately 16 feet bgs.

TABLE 3.6
MAXIMUM PRESSURE RESPONSE
AIR PERMEABILITY TEST
BUILDING 102
ELLSWORTH AFB, SOUTH DAKOTA

	Distance from injection well (feet)			
	20 (MPB)		30 (MPC)	
Depth (feet)	10	15	10	15
Time (min)	20	45	7	7
Max Press. (inches H_2O)	2.25	0.35	1.05	1.45

TABLE 3.7
INFLUENCE OF AIR INJECTION AT VENT WELL
ON MONITORING POINT OXYGEN LEVELS
BUILDING 102
ELLSWORTH AFB, SOUTH DAKOTA

MP	Distance From VW (ft)	Depth(ft)	Initial O_2(%)	Final O_2 (%) Long-term System[a/]
A	10	10	4.1	NS[b/]
B	20	10	3.1	NS
C	30	10	0.6	16.8
A	10	15	3.5	NS
B	20	15	NS	NS
C	30	15	0.5	20.0

a/ Reading taken after approximately 20.5 hours of injection using long-term blower system.
b/ NS = not samples.

testing at selected points at this site are presented in Figures 3.5 through 3.8. Additional results are included in Appendix A. Table 3.8 provides a summary of the oxygen utilization rates.

Because helium is a conservative, inert gas, the change in helium concentrations over time can be useful in determining the effectiveness of the bentonite seals between MP screened intervals. Figures 3.5 through 3.8 compare oxygen utilization and helium retention. Because the observed helium loss was negligible, and because helium will diffuse approximately three times faster than oxygen due to oxygen's greater molecular weight, the measured oxygen loss is the result of bacterial respiration and not due to faulty MP construction.

Results from this test indicate that all MP screened intervals had significant soil hydrocarbon contamination. MPB-15 was abandoned after soil gas samples could not be collected. It is assumed, based on the results from the other two 15-foot intervals, that soil at MPB-15 is also contaminated.

Oxygen loss occurred at moderate rates, ranging from 0.00043 percent per minute at MPB-10 to 0.00076 percent per minute at the VW. At the VW, the oxygen dropped from 20.2 percent to 17.0 percent in 4,210 minutes.

Based on these oxygen utilization rates, an estimated 100 to 200 mg of fuel per kg of soil can be degraded each year at this site. This conservative estimate is based on an average air-filled porosity of approximately 0.128 liter per kg of soil, and a ratio of 3.5 mg of oxygen consumed for every 1 mg of fuel biodegraded. Actual rates may exceed these estimates.

3.2.5 Potential Air Emissions

The long-term potential for air emissions from full-scale bioventing operations at this site is low because of the relatively impermeable concrete pavement covering the site and the low air injection rate. Emissions should be minimal because accumulated vapors will move slowly outward from the air injection point and will be biodegraded as they move horizontally through the soil.

The air in Building 120 was monitored for TVH both before and during air injection to confirm that TVH emissions are not entering the building as the result of injection at the VW. These monitoring results indicate that air injection will not cause elevated TVH concentrations in the building and will not create health or explosion hazards. Building air sampling results are presented in Table 3.9.

4.0 RECOMMENDATIONS

4.1 Area D

Initial bioventing tests at this site indicate that oxygen has been depleted in the contaminated soils, and that air injection is an effective method of increasing aerobic fuel biodegradation. AFCEE has recommended that air injection continue at this site to determine the long-term radius of oxygen influence and the effect of time, available nutrients, and changing temperatures on fuel biodegradation rates.

Figure 3.5
Respiration Test
Oxygen and Helium Concentrations
Building 102: MPA-15
Ellsworth AFB, South Dakota

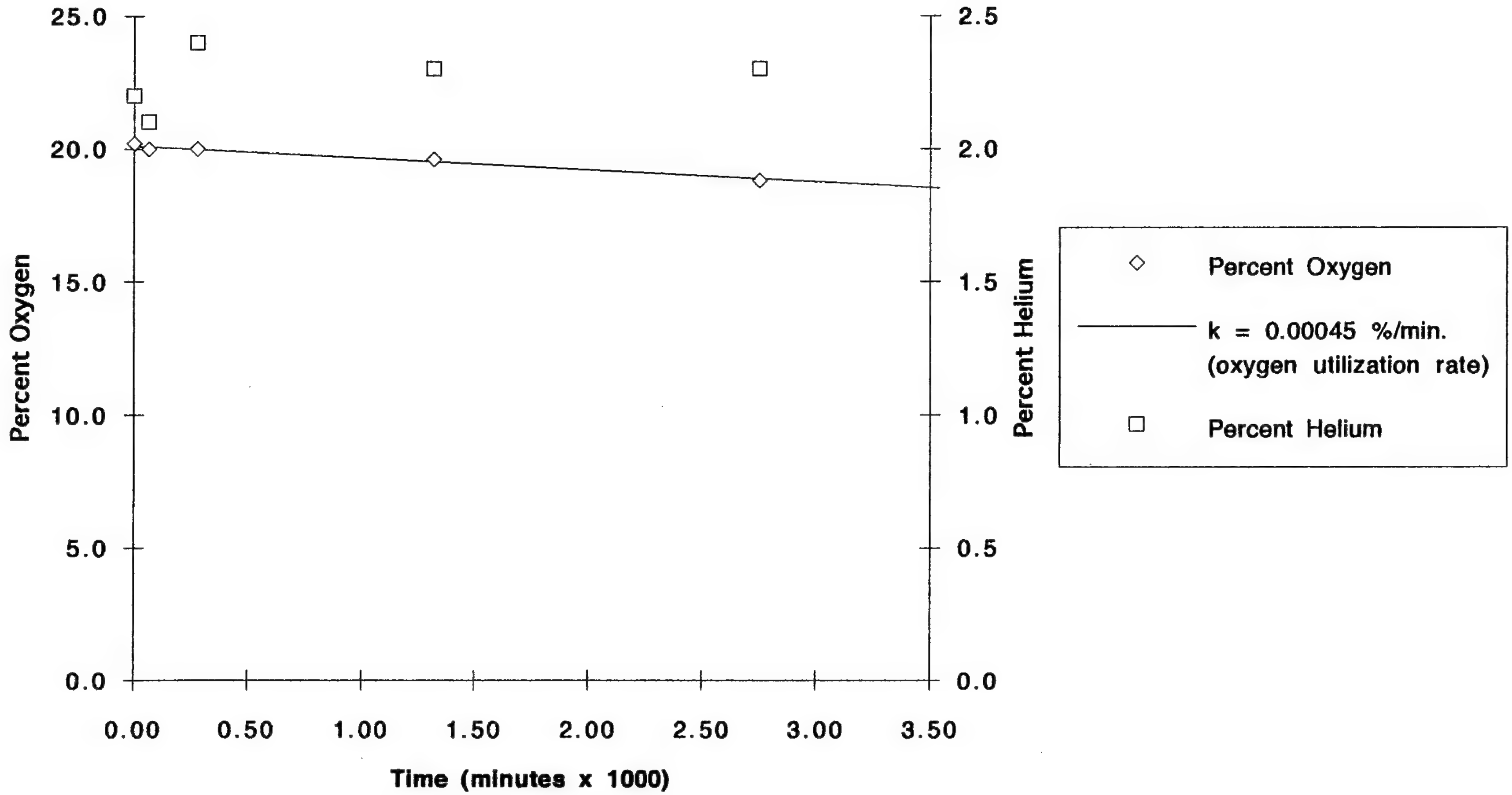


Figure 3.6
Respiration Test
Oxygen and Helium Concentrations
Building 102: MPB-10
Ellsworth AFB, South Dakota

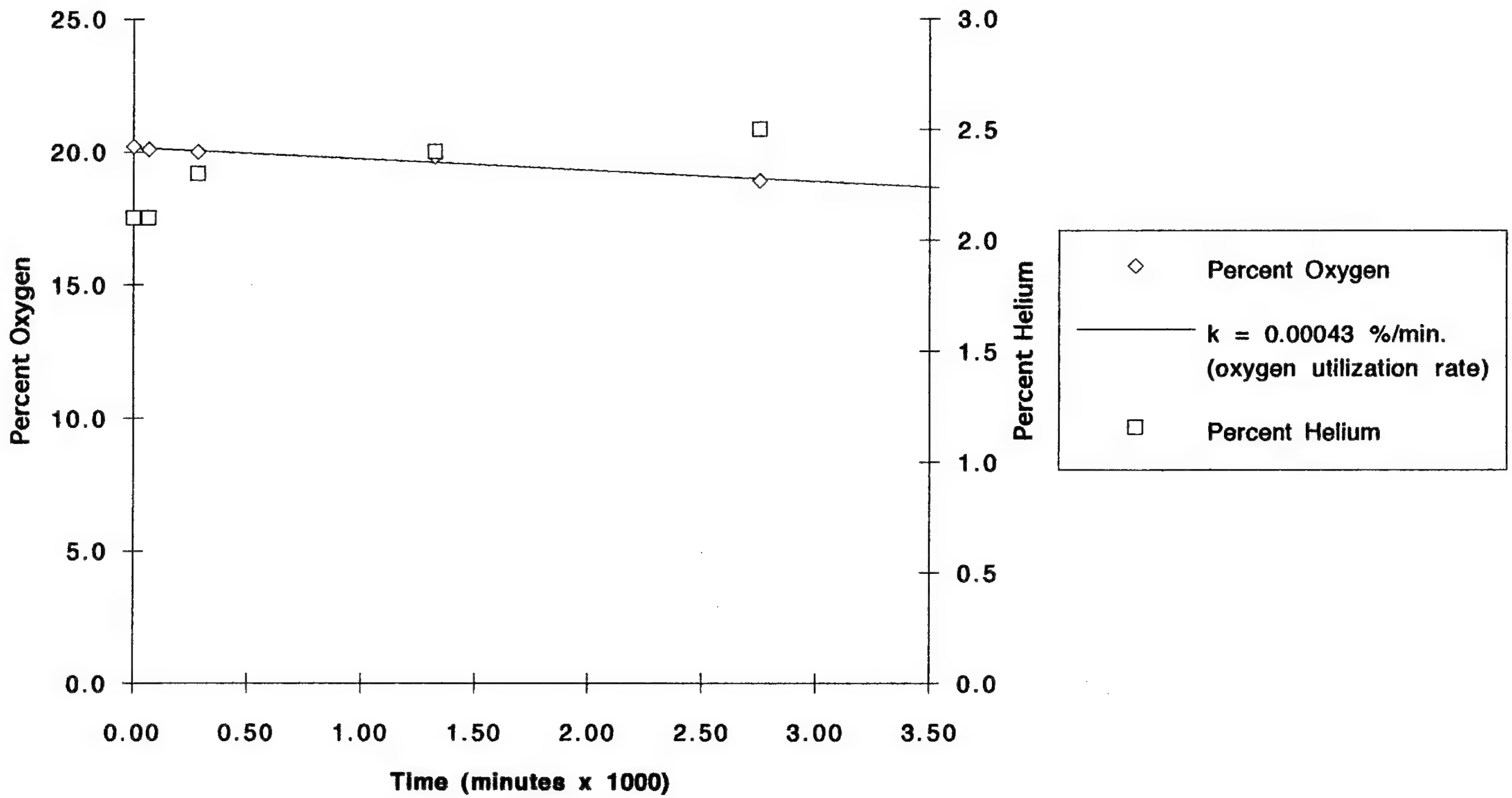


Figure 3.7
Respiration Test
Oxygen and Helium Concentrations
Building 102: MPC-15
Ellsworth AFB, South Dakota

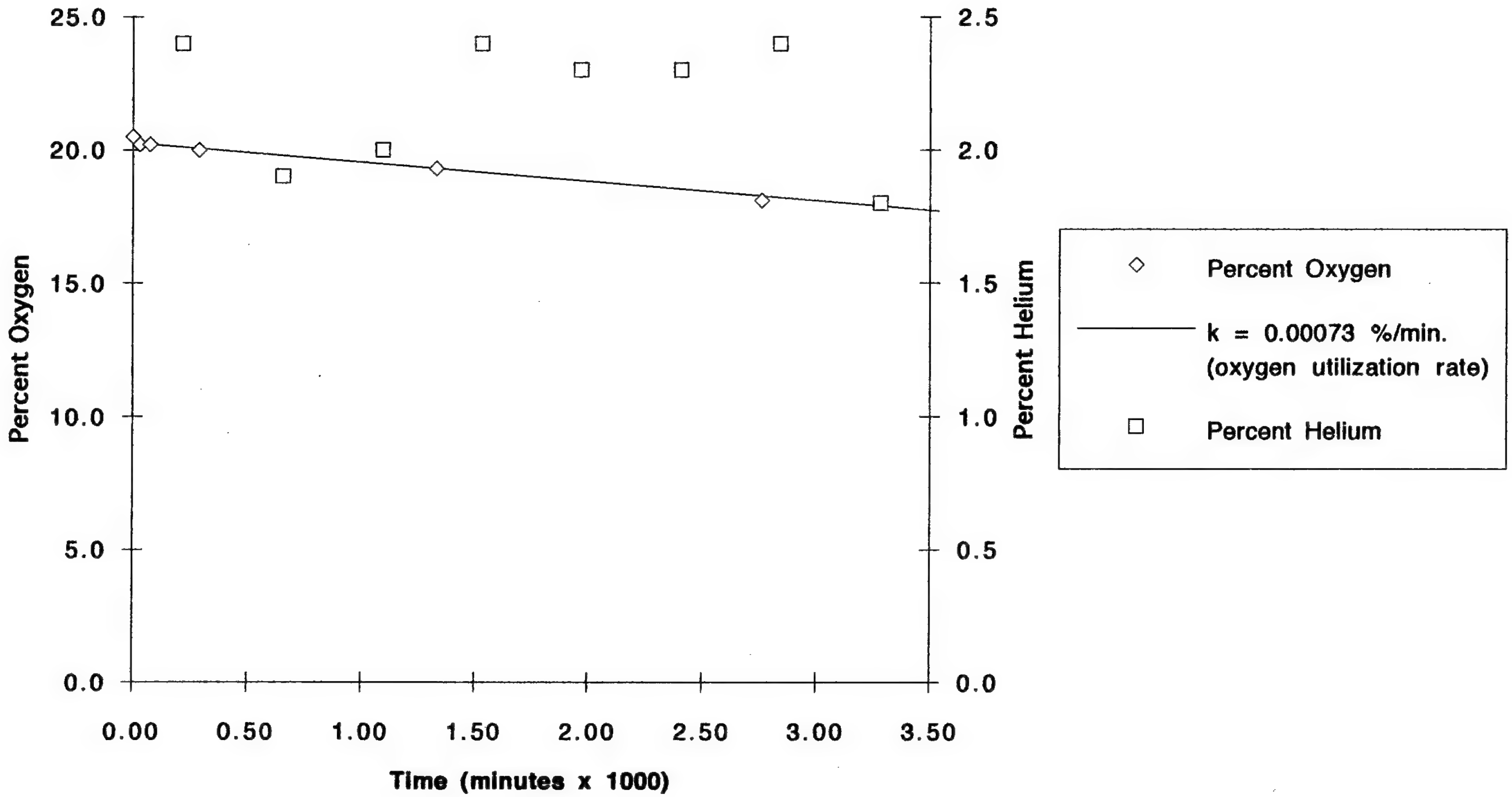


Figure 3.8
Respiration Test
Oxygen and Helium Concentrations
Building 102: VW
Ellsworth AFB, South Dakota

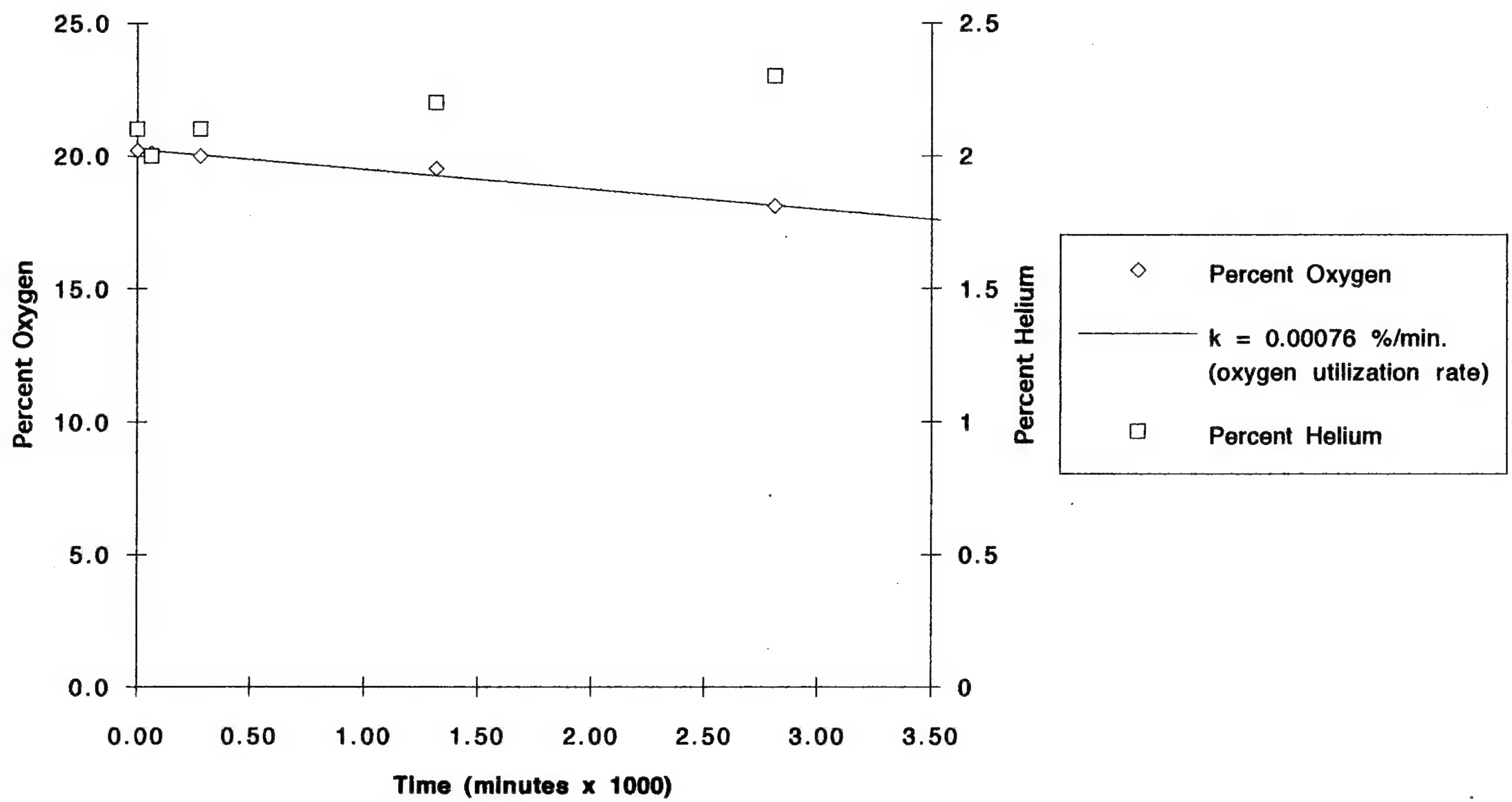


TABLE 3.8
OXYGEN UTILIZATION RATES
BUILDING 102
ELLSWORTH AFB, SOUTH DAKOTA

Location	O_2 Loss[a/] (%)	Test[b/] Duration (min)	O_2 Utilization[c/] Rate (%/min)
MPA-15	2.6	5,940	0.00045
MPB-10	2.4	5,940	0.00043
MPC-15	4.4	5,950	0.00073
VW	3.2	4,210	0.00076
MPC-10	3.2	5,950	0.00053
MPA-10	2.5	5,940	0.00046

a/ Actual measured oxygen loss.
b/ Elapsed time from beginning of test to time when minimum oxygen concentration was measured.
c/ Values based on best-fit lines (Figures 3.5 through 3.8).

TABLE 3.9
AIR MONITORING RESULTS FOR
BUILDING 102
ELLSWORTH AFB, SOUTH DAKOTA

Location	Breathing Zone TVH (ppmv) Outside	Inside
Before Air Permeability Test (8/31/93 14:00)		
Tire Shop	0.0	2.0
Drum Storage	0.0	2.0
Hallway	0.0	3.0
Battery Shop	0.0	6.0
During Air Permeability Test (9/7/93 09:15)		
Tire Shop	0.0	1.0
Drum Storage	0.0	NS[a/]
Hallway	0.0	2.0
Battery Shop	0.0	3.0

[a/] NS = not sampled.

A small, 1-horsepower regenerative blower has been installed at the site to continue air injection at a rate of approximately 48 scfm. In March 1994, ES will return to the site to sample and analyze the soil gas and conduct a repeat respiration test. In September 1994, a final respiration test will be conducted, and soil and soil gas samples will be collected from the site to determine the degree of remediation achieved during the first year of *in situ* treatment.

AFCEE/EST has selected the Area D fuel loading area for a demonstration of an innovative, risk-based remediation approach. This demonstration will be conducted by Engineering-Science, Inc. and will include an expansion of the existing bioventing system for removing the source of fuel contamination, and the use of the BioPlume II® model for measuring and predicting the future natural biodegradation of benzene and other fuel compounds in groundwater. More information and a schedule for this work will be forthcoming.

4.2 Building 102

Initial bioventing tests at this site indicate that oxygen has been depleted in the contaminated soils, and that air injection is an effective method of increasing aerobic fuel biodegradation. AFCEE has recommended that air injection continue at this site to determine the long-term radius of oxygen influence and the effect of time, available nutrients, and changing temperatures on fuel biodegradation rates.

A small, 1-horsepower regenerative blower has been installed at the site to continue air injection at a rate of approximately 10 scfm. The system is set on a timer so that the blower is injecting air from 0800 hours to 1700 hours on Wednesdays and Sundays. It was determined that 18 hours of injection a week at the site would provide adequate oxygenation of the soils without causing excess vapor migration from the site. Health and safety readings taken from inside Building 102 indicate no increase in hydrocarbon vapors at the site (Table 3.9). In March 1994, ES will return to the site to sample and analyze the soil gas and conduct a repeat respiration test. In September 1994, a final respiration test will be conducted, and soil and soil gas samples will be collected from the site to determine the degree of remediation achieved during the first year of *in situ* treatment.

AFCEE/EST has selected the Building 102 fuel loading area for a demonstration of an innovative, risk-based remediation approach. This demonstration will be conducted by Engineering-Science, Inc. and will include an expansion of the existing bioventing system for removing the source of fuel contamination, and the use of the BioPlume II® model for measuring and predicting the future natural biodegradation of benzene and other fuel compounds in groundwater. More information and a schedule for this work will be forthcoming.

5.0 REFERENCE

Hinchee, R.E., S.K. Ong., R.N. Miller, D.C. Downey, and R. Frandt. 1992. *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing.* Prepared for USAF Center for Environmental Excellence. May.

APPENDIX A
GEOLOGIC BORING LOGS,
CHAIN-OF-CUSTODY FORMS,
TEST DATA, AND CALCULATIONS

GEOLOGIC BORING LOG

BORING NO.:	VW	CONTRACTOR:	Layne Western	DATE SPUD:	8/25/93
CLIENT:	Ellsworth AFB	RIG TYPE:	Failing	DATE CMPL:	
JOB NO.:	DE268.42.04	DRLG MED:	HS	ELEVATION:	
LOCATION:	Bldg. 102	BORING DIA.:	11"	TEMP:	75
GEOLOGIST	R. Frishmuth	DRLG FLUID:	N/A	WEATHER:	Clear/Windy

Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Blow Counts	Remarks TIP = (isobutylene units)
1			Asphalt over concrete for approximately 1 foot. Dark brown silty					Log from cuttings
			CLAY with a trace of sand, slightly moist.					
5								no odor
			SAA					
			SAA					
			Gravel – drilling much harder.					
10			Drilling easier for 2 feet then back into gravel with some clay,					
			silt and sand.					
			GRAVEL with sand and clay					
15								
20								
25								
30								
35								
40								

sl – slight, tr – trace, sm – some, & – and, @ – at, w – with
v – very, kt – light, dk – dark, bf – buff, brn – brown, blk – black
NO/NS–no odor/ no stain, HSA–Hollow stem auger, SSA–Solid stem auger
fm – fine, m – medium, crs – coarse, BH – Bore Hole, SAA – Same As Above, M.S.L. – Mean Sea Level

SPLIT SPOON SAMPLE
SHELBY TUBE SAMPLE
GRAB SAMPLE
EST. WATER TABLE

GEOLOGIC BORING LOG

BORING NO.:	MPA	CONTRACTOR:	Layne Western	DATE SPUD:	8/24/93
CLIENT:	Ellsworth AFB	RIG TYPE:	Failing	DATE CMPL:	
JOB NO.:	DE268.42.04	DRLG MED:	HS	ELEVATION:	
LOCATION:	Bldg. 102	BORING DIA.:	8"	TEMP:	90
GEOLOGIST	R. Frishmuth	DRLG FLUID:	N/A	WEATHER:	Clear/Sunny

Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Blow Counts	Remarks TIP = (isobutylene units)
1			Approximately 1' of asphalt and concrete. Dark brown silty CLAY,					Log from cuttings
			slightly moist.					
5			SAA			SS	4, 5	no odor
			SAA with some sand interbedded and a trace of gravel, slightly				7, 12	HS = 120 ppm
			plastic.					
			SAA					
			Gravel, harder drilling.					
10			SAA					
			GRAVEL with silt, clay and sand dark brown to tan.			SS	9, 12	no odor
							19, 19	HS = 120 ppm
			Dark brown silty CLAY, dirling much easier.					
15			GRAVEL with silt and clay.			SS	30, 29	HS = 120 ppm
			Drilling hard again – auger refusal.					
20								
25								
30								
35								
40								

sl – slight	v – very	NO/NS–no odor/ no stain	fm – fine	SPLIT SPOON SAMPLE
tr – trace	kt – light		m – medium	
sm – some	dk – dark	HSA–Hollow stem auger	crs – coarse	SHELBY TUBE SAMPLE
& – and	bf – buff		BH – Bore Hole	
@ – at	brn – brown	SSA–Solid stem auger	SAA – Same As Above	GRAB SAMPLE
w – with	blk – black		M.S.L. – Mean Sea Level	EST. WATER TABLE

GEOLOGIC BORING LOG

BORING NO.:	MPB	CONTRACTOR:	Layne Western	DATE SPUD:	8/24/93
CLIENT:	Ellsworth AFB	RIG TYPE:	Failing	DATE CMPL:	
JOB NO.:	DE268.42.04	DRLG MED:	HS	ELEVATION:	
LOCATION:	Bldg. 102	BORING DIA.:	8"	TEMP:	90
GEOLOGIST	R. Frishmuth	DRLG FLUID:	N/A	WEATHER:	Clear/Sunny

Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Blow Counts	Remarks TIP = (isobutylene units)
1			Concrete covered by asphalt to 1 foot. Dark brown silty CLAY,					Log from cuttings
			slightly moist and plastic					
5			SAA			SS	4, 5	no odor
			SAA with some sand				8, 9	HS = 120
			SAA with more clay and less sand, moist and plastic					
10			Gravel, drilling harder					
			GRAVEL pebbles 1" and some sand, silt and clay. Auger refusal at			SS	12, 19	TD=11' no odor
			11 feet.				25, 20	HS = 110
15								
20								
25								
30								
35								
40								

sl – slight	v – very	NO/NS – no odor/ no stain	fm – fine	SPLIT SPOON SAMPLE
tr – trace	kt – light	HSA – Hollow stem auger	m – medium	SHELBY TUBE SAMPLE
sm – some	dk – dark	SSA – Solid stem auger	crs – coarse	GRAB SAMPLE
& – and	bf – buff		BH – Bore Hole	EST. WATER TABLE
@ – at	brn – brown		SAA – Same As Above	
w – with	blk – black		M.S.L. – Mean Sea Level	

GEOLOGIC BORING LOG

BORING NO.:	VW1	CONTRACTOR:	Layne Western	DATE SPUD:	8/24/93
CLIENT:	Ellsworth AFB	RIG TYPE:	Failing	DATE CMPL:	8/24/93
JOB NO.:	DE268.42.04	DRLG MED:	HS	ELEVATION:	3,250
LOCATION:	Area D	BORING DIA.:	11"	TEMP:	70
GEOLOGIST	R. Frishmuth	DRLG FLUID:	N/A	WEATHER:	Clear/Sunny

Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Blow Counts	Remarks TIP = (isobutylene units)
1			Dark brown siltly CLAY with some sand, slightly moist and plastic.					Log from cuttings
			increasing clay with depth					
5			SAA					
			Brown silty CLAY with gray staining, moist and plastic. Slightly stiff.			SS		Strong odor
			Olive/gray silty CLAY with a trace of sand, moist and plastic.					HS = 1000
10			SAA					
			Tan to brown fine SAND with gray staining, slightly moist.			SS	1, 7	
							7, 8	HS = 720
			SAA					
			GRAVEL 1" pebbles and coarse sand			SS	20, 34	Strong odor
15								
			SAA					
			Auger refusal at 17'					TD = 17'
20								
25								
30								
35								
40								

sl – slight, tr – trace, sm – some, & – and, @ – at, w – with

v – very, kt – light, dk – dark, bf – buff, brn – brown, blk – black

NO/NS – no odor/no stain, HSA – Hollow stem auger, SSA – Solid stem auger

fm – fine, m – medium, crs – coarse, BH – Bore Hole, SAA – Same As Above, M.S.L. – Mean Sea Level

SPLIT SPOON SAMPLE

SHELBY TUBE SAMPLE

GRAB SAMPLE

EST. WATER TABLE

GEOLOGIC BORING LOG

BORING NO.:	MPA	**CONTRACTOR:**	Layne Western	**DATE SPUD:**	8/23/93
CLIENT:	Ellsworth AFB	**RIG TYPE:**	Failing	**DATE CMPL:**	8/23/93
JOB NO.:	DE268.42.04	**DRLG MED:**	HS	**ELEVATION:**	3,250
LOCATION:	Area D	**BORING DIA.:**	8"	**TEMP:**	85
GEOLOGIST	R. Frishmuth	**DRLG FLUID:**	N/A	**WEATHER:**	Clear/Windy

Depth (ft.)	Pro- file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Blow Counts	Remarks TIP = (isobutylene units)
1			Dark brown SILT with some sand and gravel and a trace of clay,					Log from cuttings
			slightly moist.					
5			SAA					
			Brown silty CLAY, olive streaks and staining, moist, slightly			SS	2, 2	Slight odor, poor rec.
			stiff and plastic.				2, 4	HS = 2500
			Increasing moisture with depth.					
10			SAA					
			Light brown/olive fine SAND, not as stained as MPB, slightly moist.			SS	2, 5	Strong odor
							9, 10	HS = 9500
			SAA					
			SAA, increasing silt/clay with depth.			SS	2, 3	Strong odor
15			GRAVEL and coarse sand.				R	HS = 8400
								TD = 15'
20								
25								
30								
35								
40								

sl – slight	v – very	NO/NS–no odor/ no stain	fm – fine	SPLIT SPOON SAMPLE
tr – trace	kt – light		m – medium	
sm – some	dk – dark	HSA–Hollow stem auger	crs – coarse	SHELBY TUBE SAMPLE
& – and	bf – buff		BH – Bore Hole	
@ – at	brn – brown	SSA–Solid stem auger	SAA – Same As Above	GRAB SAMPLE
w – with	blk – black		M.S.L. – Mean Sea Level	EST. WATER TABLE

GEOLOGIC BORING LOG

BORING NO.:	MPB	CONTRACTOR:	Layne Western	DATE SPUD:	8/23/93
CLIENT:	Ellsworth AFB	RIG TYPE:	Failing	DATE CMPL:	8/23/93
JOB NO.:	DE268.42.04	DRLG MED:	HS	ELEVATION:	3,250
LOCATION:	Area D	BORING DIA.:	8"	TEMP:	90
GEOLOGIST	R. Frishmuth	DRLG FLUID:	N/A	WEATHER:	Clear/Windy

Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Blow Counts	Remarks TIP = (isobutylene units)
1			Dark brown SAND with some silt, tough drilling, very dry					Log from cuttings
			flaky cuttings.					
								No odor
5			SAA					
			Brown SILT with some sand, increasing moisture with depth,			SS	7, 4	No odor
			very stiff.				4, 7	HS = 100
			Very silty CLAY, slightly moist and plastic.					
10			SAA			SS	3, 4	Odor
			Gray, stained silty CLAY, less moist than above.				8, 8	HS = 9500
			SAA			SS	4, 5	HS = 9000
			Light brown/olive fine SAND, slight moist.				17, R	
15			GRAVEL.					
								TD = 15'
20								
25								
30								
35								
40								

sl – slight	v – very	NO/NS–no odor/ no stain	fm – fine
tr – trace	kt – light	HSA–Hollow stem auger	m – medium
sm – some	dk – dark	SSA–Solid stem auger	crs – coarse
& – and	bf – buff		BH – Bore Hole
@ – at	brn – brown		SAA – Same As Above
w – with	blk – black		M.S.L. – Mean Sea Level

SPLIT SPOON SAMPLE

SHELBY TUBE SAMPLE

GRAB SAMPLE

EST. WATER TABLE

ENGINEERING–SCIENCE

GEOLOGIC BORING LOG

BORING NO.:	MPC	CONTRACTOR:	Layne Western	DATE SPUD:	8/23/93
CLIENT:	Ellsworth AFB	RIG TYPE:	Failing	DATE CMPL:	8/23/93
JOB NO.:	DE268.42.04	DRLG MED:	HS	ELEVATION:	3,250
LOCATION:	Area D	BORING DIA.:	8"	TEMP:	80
GEOLOGIST	R. Frishmuth	DRLG FLUID:	N/A	WEATHER:	Clear/Windy

Depth (ft.)	Pro-file	USCS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Blow Counts	Remarks TIP = (isobutylene units)
1			Dark brown silty CLAY with some sand and gravel, slightly plastic					Log from cuttings
			and stiff.					
5			SAA					HS = 75 ppm
						SS	2, 2	2" of recovery
							5, 5	
						SS	2, 3	Full recovery
			SAA with increasing clay content.				5, 5	HS = 80 ppm
10								
						SS	3, 3	Strong POL odor
			SAA with some staining, increased clay content and moisture.				6, 11	HS = 2000 ppm
			Light brown/olive fine SAND with some gravel and silt, moist.					
			SAA			SS	3, 4	Strong POL odor
15			Coarse SAND/GRAVEL (1" and pebbles).				7, 17	HS = 4000 ppm
			Interbedded CLAY layers, gravel and coarse sand, very moist.			SS		Strong POL odor
								Refusal – HS=3500 ppm
			SAA					
			Weathered gray SHALE with iron staining along fractures.					
20						SS	6, 8	No odor
			SAA				12, 24	
								TD = 22'
25								
30								
35								
40								

sl – slight
tr – trace
sm – some
& – and
@ – at
w – with

v – very
lt – light
dk – dark
bf – buff
brn – brown
blk – black

NO/NS – no odor/ no stain
HSA – Hollow stem auger
SSA – Solid stem auger

fm – fine
m – medium
crs – coarse
BH – Bore Hole
SAA – Same As Above
M.S.L. – Mean Sea Level

SPLIT SPOON SAMPLE
SHELBY TUBE SAMPLE
GRAB SAMPLE
EST. WATER TABLE

@ AIR TOXICS LTD.
AN ENVIRONMENTAL ANALYTICAL LABORATORY

180 BLUE RAVINE ROAD, SUITE B
FOLSOM, CA 95630
(916) 985-1000 • FAX (916) 985-1020

CHAIN OF CUSTODY RECORD

PROJECT # DEZ68.42.04 PO # DEZ68.42.09 COLLECTED BY (Signature) Russell [signature]

REMARKS Ellsworth AFB, Building 102 Air Samples

	FIELD SAMPLE I.D.#	SAMPLING MEDIA (Tenax, Canister etc.)	DATE/TIME		ANALYSIS	VAC./PRESSURE	LAB I.D. #
01A/B	ELS2-MPC-15	Canister	8/27/93	1520	TO-3 (BTEX + TPH)	4"Hg	
02A	ELS2-VW	"	8/27/93	1608	↓	4"Hg	
03A	ELS2-MPA-15	"	8/27/93	1952		3.5"Hg	

RELINQUISHED BY: DATE/TIME	RECEIVED BY: DATE/TIME	RELINQUISHED BY: DATE/TIME	RECEIVED BY: DATE/TIME
Russell Frishmuth 9/1/93 1600	Fed Ex		[signature] ATL 9/2/93 / 10:45

LAB USE ONLY

SHIPPER NAME	AIR BILL #	OPENED BY: DATE/TIME	TEMP(°C)	CONDITION

REMARKS

AIR TOXICS LTD.
AN ENVIRONMENTAL ANALYTICAL LABORATORY

180 BLUE RAVINE ROAD, SUITE B
FOLSOM, CA 95630
(916) 985-1000 • FAX (916) 985-1020

CHAIN OF CUSTODY RECORD

PROJECT # DE268.42.04 PO # DE268.42.09 COLLECTED BY (Signature) Russell [signature]
REMARKS Ellsworth AFB - Area D, Rapid City, South Dakota

	FIELD SAMPLE I.D.#	SAMPLING MEDIA (Tenax, Canister etc.)	DATE/TIME	ANALYSIS	VAC./PRESSURE	LAB I.D. #
01A/B	ELS-1-MPA-14	CANISTER	8/26/93 1020	TO-3 (BTEX+TPH)	3.0 "Hg	
02A	ELS-1-MPC-10		8/26/93 1006		3.0 "Hg	
03A	ELS-1-VW-2		8/26/93 1015		3.0 "Hg	
04A	ELS-1-VW-1		8/26/93 1025		3.5 "Hg	

RELINQUISHED BY: DATE/TIME	RECEIVED BY: DATE/TIME	RELINQUISHED BY: DATE/TIME	RECEIVED BY: DATE/TIME
Russell [signature] 8/26/93 1500	FED EX		L. Robinson ATL 8/27/93 1106

LAB USE ONLY

SHIPPER NAME	AIR BILL #	OPENED BY: DATE/TIME	TEMP(°C)	CONDITION

REMARKS

43827.DT

Page 1 of 1

CHAIN OF CUSTODY RECORD

ENGINEERING-SCIENCE, INC.
1700 BROADWAY, SUITE 900
DENVER, COLORADO 80290
303-831-8100

ES Job No. DE268. 4 2 .08

AFCEE BIOVENTING PILOT TESTS

Base: Ellsworth AFB, Rapid City, SD

Site: Area D (1) + Bldg 102 (2)

Sampler(s): (Signature) Russell Frishmuth RUSSELL FRISHMUTH

Scott Arends SCOTT ARENDS

John F. Hall John F. Hall

Ship To:

PACE INCORPORATED
11 Digital Drive
Novato, CA 94949

Attn: Ms. Stacy Hoch
(415) 883-6100

Preservative: NONE (SW 9045, A 403, SW 7380, SW 846); HOLD (SW 8020); AT 4C (E 418.1); NONE (E 351.2, E 365.3, UCM)

Analysis Required

Date	Time	Sample Description		Lab I.D.	No. of Contrs.	SW 9045 (PH)	A 403 (ALKA)	SW 7380 (IRON)	SW 846 (MOIST)	SW 8020 (BTEX)	E 418.1 (TRPH)	E 351.2 (TKN)	E 365.3 (PHOS)	UCM (CLASS)	Sample Type	Matrix	Remarks
/23/93	1610	EL1-MPB-10	14314.4		3	✓	✓	✓	✓	✓	✓	✓	✓	✓	G C	SOIL	
8/24/93	0900	EL1-VW-5	14315.2		3	✓	✓	✓	✓	✓	✓	✓	✓	✓	G C	SOIL	
/23/93	1730	EL1-MPA-10	14316.0		3	✓	✓	✓	✓	✓	✓	✓	✓	✓	G C	SOIL	
8/24/93	0900	EL1-BG-2	14317.9		1							✓			G C	SOIL	
8/26/93	1300	EL2-VW-16	14318.7		3	✓	✓	✓	✓	✓	✓	✓	✓	✓	G C	SOIL	Composite off of augers
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	
															G C	SOIL	

Relinquished by: (Signature)	Date / Time	Recieved for Laboratory by: (Signature)	Date / Time
Russell Frishmuth	8/26/93 1630	FEDERAL EXPRESS	
Relinquished by: (Signature)	Date / Time	Recieved for Laboratory by: (Signature)	Date / Time
		J. Brown Pace	8/27/93 0945

Remarks:

G - Grab Sample, C - Composite Sample

Distribution: Original Accompanies Shipment. Copies to: Coordinator Field Files

Federal Express Number:

Airbill Number: 1968905820

ENGINEERING-SCIENCE, INC.
1700 Broadway, Suite 900 • Denver, Colorado
(303) 831-8100

CCRSOIL

Respiration Test
Area D
Ellsworth AFB, SD

Monitoring Point	Date	Days Elapsed (frac. days)	Time	Hrs elapsed (fractional days)	Days Elapsed	Elapsed Time (min. x 1000)	O2%	CO2%	Total Hydro-carbon	Helium	Comments	Trend of O2/ Time	New x-values	k
VW-1	08/27/93	0.00	09:03	0.00	0.00	0.00	19.2	0.3	830	1.6		18.9283373	0	0.01669
VW-1	08/27/93	0.00	10:09	0.05	0.05	0.07	17.9	0.2	1200	1.3		10.247874	0.52	
VW-1	08/27/93	0.00	11:02	0.08	0.08	0.12	16.8	0.2	1800	1.1				
VW-1	08/27/93	0.00	13:03	0.17	0.17	0.24	14.5	0.2	2200	1.1				
VW-1	08/27/93	0.00	17:41	0.36	0.36	0.52	10.5	0.5	3200	1.2				
VW-1	08/27/93	0.00	22:18	0.55	0.55	0.80	8.0	0.5	4000	1.6				
VW-1	08/28/93	1.00	09:52	0.03	1.03	1.49	4.0	0.5	5200	1.7		Trend of O2/	New	
												Time	x-values	0.01481
VW-2	08/27/93	0.00	09:24	0.00	0.00	0.00	20.8	0.5	300	0.0		20.8	0	
VW-2	08/27/93	0.00	10:18	0.04	0.04	0.05	20.0	0.4	240	0.0		20.0592593	0.05	
MPA-5	08/27/93	0.00	09:15	0.00	0.00	0.00	18.8	2.8	800	0.28		18.8	0	0.01818
MPA-5	08/27/93	0.00	09:59	0.03	0.03	0.04	18.0	3.5	700	0.21		18.0727273	0.04	
MPA-5	08/29/93	2.00	09:35	0.01	2.01	2.90	16.0	5.2	NS	NS	After injecting at VW overnight.			
MPA-10	08/27/93	0.00	09:11	0.00	0.00	0.00	19.0	0.2	720	1.4		Trend of O2/	New	k
MPA-10	08/27/93	0.00	09:57	0.03	0.03	0.05	17.9	0.2	1000	1.5		Time	x-values	0.01986
MPA-10	08/27/93	0.00	11:08	0.08	0.08	0.12	15.6	0.2	1400	1.3		18.4549339	0	
MPA-10	08/27/93	0.00	13:11	0.17	0.17	0.24	12.8	0.2	1700	1.1		2.96295352	0.78	
MPA-10	08/27/93	0.00	17:33	0.35	0.35	0.50	9.0	0.5	2400	1.4				
MPA-10	08/27/93	0.00	22:07	0.54	0.54	0.78	6.2	0.5	3000	1.8				
MPA-10	08/28/93	1.00	09:43	0.02	1.02	1.47	1.8	0.3	7000	1.9				
MPA-10	08/29/93	2.00	09:39	0.02	2.02	2.91	11.0	0.6	NS	NS	After injecting at VW overnight.			
MPA-14	08/27/93	0.00	09:07	0.00	0.00	0.00	19.0	0.3	400	1.4		Trend of O2/	New	k
MPA-14	08/27/93	0.00	09:53	0.03	0.03	0.05	17.8	0.3	850	1.5		Time	x-values	0.01744
MPA-14	08/27/93	0.00	11:05	0.08	0.08	0.12	15.5	0.3	1000	1.3		18.0225215	0	
MPA-14	08/27/93	0.00	13:07	0.17	0.17	0.24	12.4	0.3	1600	1.3		4.42098077	0.78	
MPA-14	08/27/93	0.00	17:29	0.35	0.35	0.50	8.9	0.5	2000	1.4				
MPA-14	08/27/93	0.00	22:09	0.54	0.54	0.78	5.1	0.5	2800	1.4				
MPA-14	08/28/93	1.00	09:38	0.02	1.02	1.47	1.8	0.4	4000	1.9				
MPA-14	08/28/93	1.00	13:32	0.18	1.18	1.71	20.4	0.5	NS	NS	After 1 hour perm.	Trend of O2/	New	k
												Time	x-values	-0.0351
MPB-5	08/27/93	0.00	08:53	0.00	0.00	0.00	19.1	2.6	580	0.31		19.1	0	
MPB-5	08/27/93	0.00	09:50	0.04	0.04	0.06	19.3	2.5	360	0.24		20.5035088	0.4	
MPB-5	08/29/93	2.00	09:42	0.03	2.03	2.93	19.5	2.6	NS	NS				
MPB-10	08/27/93	0.00	08:50	0.00	0.00	0.00	19.0	1.4	10000	0.48		19	0	-0.0357
MPB-10	08/27/93	0.00	09:46	0.04	0.04	0.06	19.2	1.6	7000	0.27		20.4285714	0.4	
MPB-10	08/29/93	2.00	09:45	0.04	2.04	2.94	19.2	1.8	NS	NS				

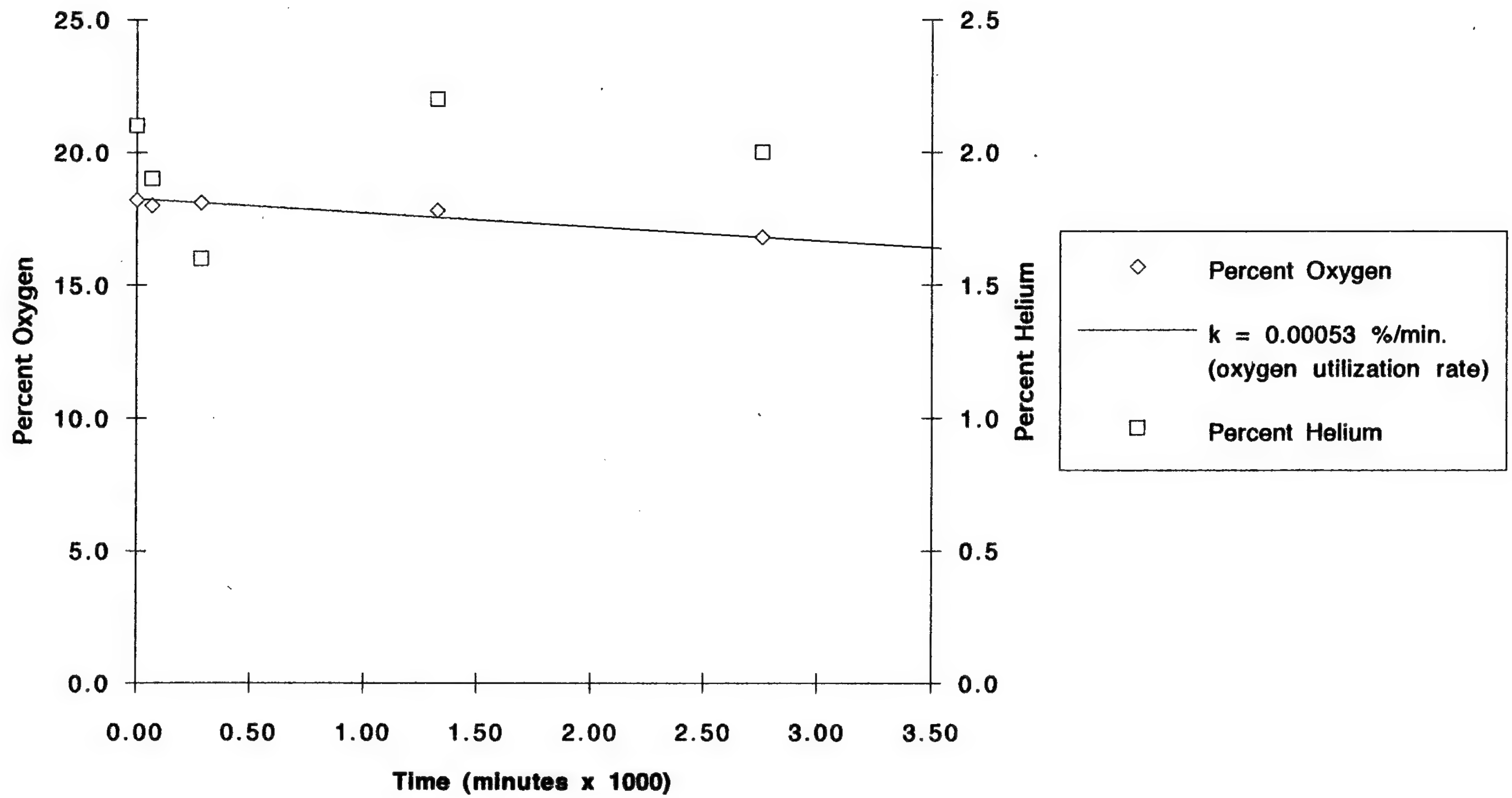
MPB-14	08/27/93	0.00	08:46	0.00	0.00	0.00	19.2	0.3	200	1.7		Trend of O2/	New	k	
MPB-14	08/27/93	0.00	09:43	0.04	0.04	0.06	17.8	0.2	520	1.5		Time	x-values	0.01801	
MPB-14	08/27/93	0.00	10:47	0.08	0.08	0.12	15.5	0.5	1000	1.1		18.1836338	0		
MPB-14	08/27/93	0.00	12:46	0.17	0.17	0.24	12.6	0.2	1000	1.4		3.77171567	0.8		
MPB-14	08/27/93	0.00	17:23	0.36	0.36	0.52	8.0	0.5	1400	1.4					
MPB-14	08/27/93	0.00	22:03	0.55	0.55	0.80	4.8	0.5	2100	1.7					
MPB-14	08/28/93	1.00	09:34	0.03	1.03	1.49	1.5	0.5	2800	1.7					
MPB-14	08/28/93	1.00	13:33	0.20	1.20	1.73	18.5	0.5	NS	NS	After 1 hour perm.				
MPC-5	08/27/93	0.00	08:40	0.00	0.00	0.00	20.1	0.5	240	0.47		20.1	0	0	
MPC-5	08/27/93	0.00	09:40	0.04	0.04	0.06	20.1	0.5	270	0.28		20.1	0.4		
MPC-5	08/29/93	2.00	09:49	0.05	2.05	2.95	21.0	0.5	NS	NS					
MPC-10	08/27/93	0.00	08:37	0.00	0.00	0.00	20.2	0.3	280	0.70		Trend of O2/	New	k	
MPC-10	08/27/93	0.00	09:36	0.04	0.04	0.06	20.5	0.2	100	0.22		Time	x-values	-0.0001	
MPC-10	08/27/93	0.00	10:36	0.08	0.08	0.12	20.0	0.0	120	0.27		20.249446	0		
MPC-10	08/27/93	0.00	12:37	0.17	0.17	0.24	20.5	0.2	NS	NS		20.4314227	1.56		
MPC-10	08/27/93	0.00	17:20	0.36	0.36	0.52	20.0	0.5	330	0.14					
MPC-10	08/27/93	0.00	21:59	0.56	0.56	0.80	20.5	0.5	120	0.14					
MPC-10	08/28/93	1.00	09:29	0.04	1.04	1.49	20.5	0.5	180	0.0					
MPC-10	08/29/93	2.00	09:51	0.05	2.05	2.95	20.7	0.5	NS	NS					
MPC-14	08/27/93	0.00	08:32	0.00	0.00	0.00	6.1	5.2	8200	1.6		Trend of O2/	New	k	
MPC-14	08/27/93	0.00	09:34	0.04	0.04	0.06	2.9	5.2	4800	1.4		Time	x-values	-0.0006	
MPC-14	08/27/93	0.00	10:42	0.09	0.09	0.13	1.5	NS	3100	1.3		2.3771814	0		
MPC-14	08/27/93	0.00	12:33	0.17	0.17	0.24	0.5	5.5	3000	1.4		3.49693915	1.74		
MPC-14	08/27/93	0.00	17:16	0.36	0.36	0.52	0.5	6.5	4400	1.5					
MPC-14	08/28/93	1.00	13:34	0.21	1.21	1.74	4.5	5.0	NS	NS					

Respiration Test
Bldg. 102
Ellsworth AFB, SD

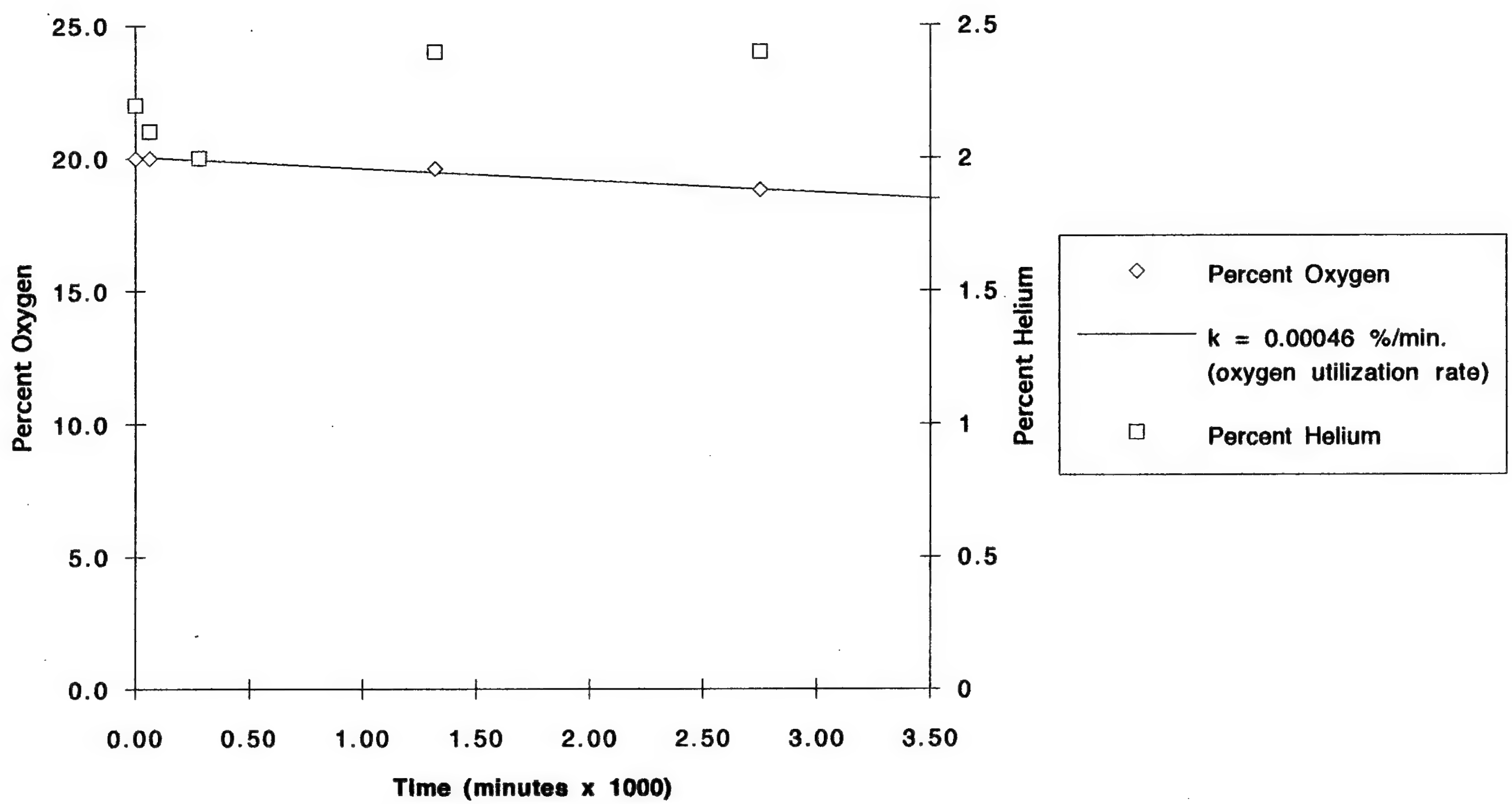
Monitoring Point	Date	Days Elapsed (frac. days)	Time	Hrs elapsed (fractional days)	Days Elapsed	Elapsed Time (min. x 1000)	O2%	CO2%	Total Hydro-carbon	Helium	Comments	Trend of O2/ Time	New x-values	k
VW	08/28/93	0.00	11:03	0.00	0.00	0.00	20.2	0.05	80	2.1		20.2425239	0	0.00076
VW	08/28/93	0.00	12:05	0.04	0.04	0.06	20.1	0.05	160	2.0		17.0634945	4.21	
VW	08/28/93	0.00	15:42	0.19	0.19	0.28	20.0	0.6	400	2.1				
VW	08/29/93	1.00	09:00	-0.09	0.91	1.32	19.5	0.7	1440	2.2				
VW	08/30/93	2.00	09:54	-0.05	1.95	2.81	18.1	1.0	2000	2.3				
VW	08/31/93	3.00	09:15	-0.08	2.93	4.21	17.0	1.2	3600	2.3				
												Trend of O2/	New	k
MPA-10	08/28/93	0.00	10:56	0.00	0.00	0.00	20.0	0.05	36	2.2		Time	x-values	0.00046
MPA-10	08/28/93	0.00	11:58	0.04	0.04	0.06	20.0	0.05	60	2.1		20.0618384	0	
MPA-10	08/28/93	0.00	15:36	0.19	0.19	0.28	20.0	0.5	210	2.0		17.3569612	5.94	
MPA-10	08/29/93	1.00	08:54	-0.08	0.92	1.32	19.6	0.5	720	2.4				
MPA-10	08/30/93	2.00	08:47	-0.09	1.91	2.75	18.8	0.5	1720	2.4				
MPA-10	08/31/93	3.00	09:12	-0.07	2.93	4.22	17.9	0.5	800	2.4				
MPA-10	09/01/93	4.00	13:55	0.12	4.12	5.94	17.5	0.7	5200	2.0				
MPA-15	08/28/93	0.00	10:53	0.00	0.00	0.00	20.2	0.05	124	2.2		Trend of O2/	New	k
MPA-15	08/28/93	0.00	11:57	0.04	0.04	0.06	20.0	0.05	220	2.1		Time	x-values	0.00045
MPA-15	08/28/93	0.00	15:33	0.19	0.19	0.28	20.0	0.5	480	2.4		20.1074606	0	
MPA-15	08/29/93	1.00	08:52	-0.08	0.92	1.32	19.6	0.6	1800	2.3		17.4365705	5.94	
MPA-15	08/30/93	2.00	08:45	-0.09	1.91	2.75	18.8	0.7	4000	2.3				
MPA-15	08/31/93	3.00	09:10	-0.07	2.93	4.22	18.0	0.8	6000	2.4				
MPA-15	09/01/93	4.00	13:53	0.13	4.13	5.94	17.6	0.8	11200	2.0				
MPB-10	08/28/93	0.00	10:48	0.00	0.00	0.00	20.2	0.05	44	2.1		Trend of O2/	New	k
MPB-10	08/28/93	0.00	11:54	0.05	0.05	0.07	20.1	0.05	84	2.1		Time	x-values	0.00043
MPB-10	08/28/93	0.00	15:31	0.20	0.20	0.28	20.0	0.5	240	2.3		20.1629511	0	
MPB-10	08/29/93	1.00	08:50	-0.08	0.92	1.32	19.8	0.5	1040	2.4		17.6213326	5.94	
MPB-10	08/30/93	2.00	08:42	-0.09	1.91	2.75	18.9	0.6	2600	2.5				
MPB-10	08/31/93	3.00	09:05	-0.07	2.93	4.22	18.1	0.6	4800	2.6				
MPB-10	09/01/93	4.00	13:51	0.13	4.13	5.94	17.8	0.7	8200	1.9				
MPC-10	08/28/93	0.00	10:43	0.00	0.00	0.00	18.2	4.8	8600	2.1		Trend of O2/	New	k
MPC-10	08/28/93	0.00	11:51	0.05	0.05	0.07	18.0	3.7	6400	1.9		Time	x-values	0.00053
MPC-10	08/28/93	0.00	15:28	0.20	0.20	0.29	18.1	3.4	6000	1.6		18.2383024	0	
MPC-10	08/29/93	1.00	08:47	-0.08	0.92	1.32	17.8	3.5	6400	2.2		15.11264	5.95	
MPC-10	08/30/93	2.00	08:40	-0.09	1.91	2.76	16.8	3.6	6800	2.0				
MPC-10	08/31/93	3.00	09:00	-0.07	2.93	4.22	16.1	3.7	7000	2.2				
MPC-10	09/01/93	4.00	13:49	0.13	4.13	5.95	15.0	3.8	9200	1.7				

MPC-15	08/28/93	0.00	10:35	0.00	0.00	0.00	20.5	0.05	NA	2.4	HC meter reads negative.	Trend of O2/	New	k
MPC-15	08/28/93	0.00	11:04	0.02	0.02	0.03	20.2	0.05	NA	1.9	HC meter reads negative.	Time	x-values	0.00073
MPC-15	08/28/93	0.00	11:50	0.05	0.05	0.08	20.2	0.05	20	2.0		20.2676692	0	
MPC-15	08/28/93	0.00	15:26	0.20	0.20	0.29	20.0	0.05	192	2.4		16.9937415	4.51	
MPC-15	08/29/93	1.00	08:45	-0.08	0.92	1.33	19.3	0.5	1300	2.3				
MPC-15	08/30/93	2.00	08:37	-0.08	1.92	2.76	18.1	0.6	2800	2.3				
MPC-15	08/31/93	3.00	08:55	-0.07	2.93	4.22	17.1	0.8	4400	2.4				
MPC-15	09/01/93	4.00	13:47	0.13	4.13	5.95	16.1	0.8	7600	1.8				

Respiration Test
Oxygen and Helium Concentrations
Building 102: MPC-10
Ellsworth AFB, South Dakota



Respiration Test
Oxygen and Helium Concentrations
Building 102: MPA-10
Ellsworth AFB, South Dakota



Ellsworth AFB – Area D
Steady–state Equation – Air Injection

Enter data

Calculated data

$$k = \frac{Q \mu \ln(Rw/Ri)}{H \pi Patm[1 - (Pw/Patm)^2]}$$

Where:

Q = Volumetric flow rate of vent well

14.5 scfm x $(30.48\ cm/ft)^3$ x (1 min/60 s) =	6.84E+03	cm^3/s
μ = Viscosity of Air @ 18° C =	1.80E–04	g/cm s

Patm = Ambient pressure @ 4800 feet of elevation

364 inches H2O x (3.61E–2 psia/in. H2O) =	13.140	psia
13.140 psia x (6.89476E4 g/cm s^2)/psia =	9.06E+05	g/cm s^2

Rw = Radius of Vent Well

2 inches x 2.54 cm/in =	5.08	cm

H = Depth of Screen (length of screened interval)

12 feet x 30.48 cm/ft =	366	cm

Ri = Maximum Radius of Venting Influence

25 feet x 30.48 cm/ft =	762	cm

Pw = Absolute Pressure at Vent Well

– inches H2O x (3.61E–2 psia/in. H2O) =	2.700	psia
2.700 psia + 13.140 psia =	15.840	psia
15.840 psia x (6.89476E4 g/cm s^2)/psia =	1.09E+06	g/cm s^2
k =	1.308E–08	cm^2
1.310E–08 cm^2 x $(1\ m/100\ cm)^2$ =	1.300E–12	m^2
1.300E–12 m^2 x 1 darcy/(9.870E–13 m^2) =	1.32	darcys

aftio3/eafb2_ss1.wk1/11–2–93

Ellsworth AFB – Bldg. 102
Steady–state Equation – Air Injection

Enter data

Calculated data

$$k = \frac{Q \mu \ln(Rw/Ri)}{H \pi Patm [1 - (Pw/Patm)^2]}$$

Where:

Q = Volumetric flow rate of vent well

40.0	scfm x $(30.48\ cm/ft)^3$ x (1 min/60 s) =	1.89E+04	cm^3/s

μ = Viscosity of Air @ 18° C = 1.80E–04 g/cm s

Patm = Ambient pressure @ 3206 feet of elevation

364	inches H2O x (3.61E–2 psia/in. H2O) =	13.140	psia
13.140	psia x (6.89476E4 g/cm s^2)/psia =	9.06E+05	g/cm s^2

Rw = Radius of Vent Well

1	inches x 2.54 cm/in =	2.54	cm

H = Depth of Screen (length of screened interval)

10	feet x 30.48 cm/ft =	305	cm

Ri = Maximum Radius of Venting Influence

30	feet x 30.48 cm/ft =	914	cm

Pw = Absolute Pressure at Vent Well

28	inches H2O x (3.61E–2 psia/in. H2O) =	1.011	psia
1.011	psia + 13.140 psia =	14.151	psia
14.151	psia x (6.89476E4 g/cm s^2)/psia =	9.76E+05	g/cm s^2

	k =	1.443E–07	cm^2
1.443E–07	cm^2 x $(1\ m/100\ cm)^2$ =	1.440E–11	m^2
1.440E–11	m^2 x 1 darcy/(9.870E–13 m^2) =	14.59	darcys

afbio3/eafb1_ss1.wk1/11–2–93

Ellsworth AFB – Area D
Biodegradation Rate Calculations

enter data	calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPA–10 K_o = max. observed rate 0.01986 %/min.
w = moisture content 13 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	*n* =	0.35
Unit weight (dry):	^{g}d =	1.72
Void ratio:	*e = n/(1–n)* =	0.54
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
V_v = 0.35 liters V_v = void volume

b) $S_r = Gw/e$
S_r = 0.64 S_r = degree of saturation

c) $V_w = S_r \times V_v$
V_w = 0.22 liters V_w = volume of water

d) $V_a = V_v - V_w$
V_a = 0.13 liters V_a = volume of air

e) Bulk density = $^{g}d + (V_w \times {}^{g}w)$ = 1.9 kg/l soil

f) A = V_a/Bulk density = 0.068 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times 525{,}600$ min/yr = 2720 mg TPH/year

afcee3/eafb_kb1.wk1/11–2–93

Ellsworth AFB – Area D
Biodegradation Rate Calculations | enter data | calculated data |

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: VW–1 K_o = max. observed rate 0.01669 %/min.
w = moisture content 15 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	*n* =	0.35
Unit weight (dry):	ᵍd =	1.72
Void ratio:	*e = n/(1–n)* =	0.54
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
V_v = 0.35 liters V_v = void volume

b) $S_r = Gw/e$
S_r = 0.74 S_r = degree of saturation

c) $V_w = S_r \times V_v$
V_w = 0.26 liters V_w = volume of water

d) $V_a = V_v - V_w$
V_a = 0.09 liters V_a = volume of air

e) Bulk density = ᵍd + (V_w x ᵍw) = 2 kg/l soil

f) A = V_a/Bulk density = 0.045 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 1510 mg TPH/year

afcee3/eafb_kb2.wk1/11–2–93

Ellsworth AFB – Building 102
Biodegradation Rate Calculations

enter data	calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: VW

K_o = max. observed rate 0.00076 %/min.

w = moisture content 7 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	$n =$	0.35
Unit weight (dry):	$\gamma d =$	1.72
Void ratio:	$e = n/(1-n) =$	0.54
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.

Solving for 1 liter of soil

a) $V_v = n * 1$ L

V_v = 0.35 liters V_v = void volume

b) $S_r = Gw/e$

S_r = 0.34 S_r = degree of saturation

c) $V_w = S_r \times V_v$

V_w = 0.12 liters V_w = volume of water

d) $V_a = V_v - V_w$

V_a = 0.23 liters V_a = volume of air

e) Bulk density = $\gamma d + (V_w \times \gamma w)$ = 1.8 kg/l soil

f) A = V_a/Bulk density = 0.128 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 200 mg TPH/year

afcee3/eafb_kb3.wk1/11-2-93

Ellsworth AFB – Building 102
Biodegradation Rate Calculations

enter data	calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density = 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPB–10 K_o = max. observed rate 0.00043 %/min.
w = moisture content 8 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	*n* =	0.35
Unit weight (dry):	ᵍd =	1.72
Void ratio:	*e = n/(1–n)* =	0.54
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
V_v = 0.35 liters V_v = void volume

b) $S_r = Gw/e$
S_r = 0.39 S_r = degree of saturation

c) $V_w = S_r \times V_v$
V_w = 0.14 liters V_w = volume of water

d) $V_a = V_v - V_w$
V_a = 0.21 liters V_a = volume of air

e) Bulk density = ᵍd + (V_w x ᵍw) = 1.9 kg/l soil

f) A = V_a/Bulk density = 0.111 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 100 mg TPH/year

afcee3/eafb_kb4.wk1/11–2–93

APPENDIX B
O&M CHECKLIST

BLOWER INJECTION SYSTEM DATA COLLECTION SHEET

SITE:________

DATE	TIME	INLET VACUUM (IN. WATER)	OUTLET TEMP. (DEGREES F)	OUTLET PRESSURE (IN. WATER)	FILTER CHANGED (Y or N)	BLOWER FUNCTIONING UPON ARRIVAL (Y or N)	COMMENTS	CHECKED BY